DD

Imperial College (London) High Energy Physics

Decay Time of Light Emission from Cerium Doped Scintillating Glass

C.Angelini³, W.Beusch¹, D.J.Crennell⁵, M.De Vincenzi⁴, A.Duane², J.P.Fabre¹, V.Flamini³, A.Frenkel⁴, T.Gys¹, K.Harrison², E.Lamanna⁴, H.Leutz¹, G.Martellotti⁴, J.G.McEwen⁶, D.R.O.Morrison¹, G.Penso⁴, S.Petrera⁴, M.Primout¹, C.Roda³, A.Sciubba⁴, E.Vicari¹ and D.M.Websdale².

¹ CERN, Geneva, Switzerland.

² Imperial College, London, UK.

³ Università di Pisa and INFN, Pisa, Italy.

⁴ Università di Roma 'La Sapienza' and INFN, Rome, Italy.

⁵ Rutherford Appleton Laboratory, Didcot, UK.

⁶ University of Southampton, UK.

Abstract

The Cerium doped scintillating glass GS1 has previously been reported to have a fast emission decay time of about 50ns. Here measurements are reported which show that the decay is much slower and has a very long tail up to one millisecond. A fit to the decay time distribution requires many components, indicating that the emission of light is a complex process. Varying the percentage of Cerium content and annealing temperature of the glass did not change the time characteristics. These results mean that GS1 glass is unsuitable for high rate counting experiments.

(Submitted to Nuclear Instruments and Methods in Physics Research)

CERN LIBRARIES, GENEVA

CM-P00062839

1. Introduction

The requirement of high energy physics experiments for precise tracking detectors combined with recent advances of optoelectronic technology has resulted in a renewed effort to develop and use scintillating fibre (SCIFI) detectors [1]. The particular application we consider in this paper concerns active targets, made from SCIFI with dimensions of the order 20 - 40 μm , which allow good spatial precision in the tracking of ionizing particles close to the region of a high energy interaction. Such targets have been proposed for studying the production and decay of beauty flavoured particles [1,2]. Developments using such thin fibres have so far concentrated on the use of glass, doped with a scintillating material such as Cerium, Terbium or Praseodymium [2,3,4].

We report results from measurements of the decay time of light emission from several samples of GS1 Cerium doped glass. The GS1 glass is considered to provide a fast response in the sense that its decay time is of order 50ns [4,5]. Our measurements, using a β -source to excite the scintillator, indicate the presence of a slow component of significant intensity. This feature is important as it seriously limits the beam intensity which can be used in an experiment.

2. Experimental Procedure

The decay time of the light emitted by the Cerium doped glass scintillators has been measured using bulk samples coupled to a photomultiplier. The samples were irradiated with a β -emitting source (^{106}Ru), appropriately shielded to avoid direct irradiation of the photocathode window. Two methods were used. The first one described uses delayed pulse height analysis and provides data up to a delay of 60 μs . The second method counts individual photoelectrons and provides data over the range 0.5 μs - 1000 μs following the prompt light emission.

Method I uses the set-up shown in figure 1. A sample (25 x 25 x 4mm³) of GS1 glass with composition by weight [SiO₂ : 55%, MgO : 24%, Al₂O₃ : 11%, Li₂O : 6%, Ce₂O₃ : 4%] was coupled directly to the window of an RCA 8850 QUANTACON photomultiplier. The spectral response of the bialkali photocathode is well matched to the emission spectrum of the GS1 glass [4]. The signal from the photomultiplier anode is divided into two parts. The first is sent to a threshold discriminator which opens the gates of two charge sensing analogue-to-digital converters (ADC's). The second part is equally divided and sent to the linear input of each ADC. Signal timings are indicated on the figure. ADC1 measures the prompt charge pulse while ADC2 measures that part of the charge arriving during the delayed gate. In order to reduce the pulse height fluctuations, only a limited range of pulse heights recorded by ADC1 was used in the analysis.

In figure 2 we present a typical ADC2 spectrum obtained using a gate delay of 5 μ s. The pedestal (zero), single photoelectron and two photoelectron peaks are clearly visible. Small variations of the pedestal position with the gate delay are corrected for in the analysis. They correspond to a variation of the baseline of ADC2 of the order of 0.1mV.

With the set-up just described we measured the decay time of light emitted by the GS1 sample and, for comparison, by NE102A plastic scintillator and by a fast (5ns rise-time) red light emitting diode (LED). The duration of the ADC2 gate was 20ns or 200ns (respectively at the shorter and the longer delay times) and its delay varied between 0 and 60 μ s.

Method II uses a similar set-up but instead of measuring charge arriving in a delayed gate the photoelectrons are individually counted using a scaler. The signal used for the ADC2 input (see figure 1) is amplified (ORTEC-474 with 50ns integration time), discriminated and scaled in coincidence with the delayed gate. This method does not work for the prompt emission, where the individual photoelectron signals are superposed, but it is a simpler measurement for longer delays. To allow measurements up to delay times of 1ms a very weak source (100 Bq) was used. This avoided significant corrections of the rates due to accidental coincidences with photoelectrons from uncorrelated light emission.

We measured the decay time of light emitted from six different samples of GS1 glass. The samples labelled GS1/0,/2,/3,/4 contained respectively 0%,2%,3%,4% by weight of Ce₂O₃. Samples GS1/4a and GS1/4b (from the same production melt as GS1/4) had been annealed at 600°C and 650°C respectively for 16 hours; the other samples were not annealed. For these measurements the width of the gate was 50ns or 1000ns (at the shorter and the longer delay times) and its delay varied between 0.5 μ s and 1000 μ s.

3. Results

3.1 Emission time characteristics

The main result from the delayed pulse height analysis is shown in figure 3. A single time constant of order 50ns fails to describe the light emission from the GS1 glass (the measurement shown here is from sample GS1/2). A slow component is clearly evident. The NE102A also exhibits, at a much lower level, a slow component. The existence of such a component in NE102A was previously reported, but measured only up to 120ns [6]. As a check we have also measured the time response to a fast rise time LED, triggered with a 5ns wide pulse. The data are included on figure 3. The much faster decrease in light emission

observed from the LED, compared to that from the scintillators indicates that the observed long tails are a real effect. The peak which occurs at a delay of 400-600ns, which is due to afterpulses[7] of the photomultiplier, affects only slightly the NE102A measurements and its magnitude is negligible for the GS1 light emission.

We show in figure 4 pulse height data from GS1 over the delay range covered using method I. The curve fit to the plot requires four components. The principal component is fast, with a characteristic decay time of 74ns, but this accounts for only 35% of the light emitted.

The next series of results compares the different GS1 samples and was obtained by counting individual photoelectrons as described for method II. As a check we first compare the data from a sample of GS1/4 (4% Cerium by weight) obtained using both methods I and II. As seen in figure 5, over the range 1 - 40 μ s the agreement is good. (Below 1 μ s the counting method saturates due to pile-up and above 40 μ s the pulse height analysis suffers from background problems).

An overall fit to the data of the form:

$$I = \sum A_i \exp(-t/\tau_i) \quad (i = 1,5)$$

gave:					
$A_i =$	637	148	9.2	0.94	0.067
$\tau_i =$	71ns	264ns	2.49 μ s	18.6 μ s	349 μ s
					

Curves corresponding to the five terms are indicated on figure 5, together with the overall fit.

Emission time characteristics which are wavelength dependent have been reported for Terbium and Cerium glasses [3]. We found no evidence for a difference in wavelengths between the fast and the slow components from GS1. Using a narrow band filter (Melles Griot 03 FIV 026) that transmits between 390 and 420 nm (ie. in the central region of the GS1 emission spectrum) we obtained data in agreement with those of figure 5.

In figure 6 we compare the light emission time characteristic of the long lived components from the various GS1 samples. Each sample is displaced by one decade on the vertical scale, otherwise the data points would be indistinguishable. We detect no difference depending on Cerium content (2, 3, 4% by weight) nor in the two annealed samples, which retain the long lived emission. Data from the

sample containing no Cerium is not shown in the figure as the rates were independent of the gate delay and compatible with the background count rate. Finally, in figure 7, we show the cumulative light emission; ie. that fraction of the total light which is emitted within a given time of the prompt ionization deposition.

The GS1/2 sample was also irradiated with α -particles from a ^{241}Am source. The decay time characteristics of the scintillation light were no different from those observed when using the β -source so the effect is not noticeably dependent on the density of ionization energy deposited.

3.2 Scintillation light yield

The scintillation light yield of GS1 glass has been compared with that from plastic scintillator for a given energy deposition. A measurement of about 15% has been previously reported[4] for this ratio. In view of the results above the measurement is evidently dependent on the integration time used in the comparison.

The light yield from cosmic-ray muons traversing a GS1/2 sample was compared with an NE102A sample of identical geometry (a disc, 10mm thick x 25mm diameter). The integrated light emitted up to 1ms represents $50 \pm 10\%$ of the light emitted by the NE102A sample (normalised to the same energy deposition). This result was confirmed in a measurement of the average current at the anode of the photomultiplier when the samples were exposed to a β -source.

The scintillation light emitted by GS1 when exposed to the α -source was however significantly reduced with respect to that from minimum ionizing particles (mip). We compared the pulse height from α -particles depositing 3.65 MeV (measured using a depleted silicon detector) in the sample with that from traversing cosmic-ray muons, which deposit 4.5 MeV. Normalising to the same energy deposition we find the ratio $(\alpha/\text{mip}) = 0.24 \pm 0.03$. This result was obtained using gate widths in the range 100ns to 1000ns for the pulse height analysis. A similar measurement using the NE102A sample gave $(\alpha/\text{mip}) = 0.10 \pm 0.015$, consistent with other reported measurements [4,8].

4. Discussion and Conclusions

We have measured a significant slow component in the light emission from GS1 scintillating glass when irradiated with β and α -sources. The intensity of light in this component is independent of the Ce_2O_3 content (in the range 2 - 4 % by weight), and is observed to be present in different production melts.

Although this result is contrary to statements in recent publications [4,5]

the data are not, in fact, in conflict. The result reported in [4] was based on observations limited to short (~ 300 ns) delays while the result in [5] is based on excitation of the GS1 glass (referred to as SC20) by laser light at 337nm. It was long ago observed [9] that excitation by UV light of a GS1-type Cerium doped glass (referred to as NE901) resulted in a simple exponential decay time characteristic, but that excitation by neutrons and charged particles resulted in a more complex decay. Although published measurements extend only to 150ns the authors of [9] state that the pulses also showed "A long tail of small amplitude which persisted for several microseconds". The explanation proposed is that UV light excites the Cerium directly while the ionization energy which is deposited in the glass matrix by charged particles has to be transferred to the luminescent Cerium ions. The role of defects as energy traps could be significant. As this condition may be associated with local strain in the glass the annealing procedures were tried in the hope of reducing traps. Owing to the tendency of the glass to devitrify annealing had to be applied with caution. A 650°C anneal showed no observable improvement in the emission time characteristics.

This slow emission severely limits the beam intensity which can be used in an experiment with a SCIFI target made from GS1 glass. The use of a gated optoelectronics chain will not avoid background on the image due to emission from previous beam particle interactions. This has been observed in tests performed using a 340 GeV/c pion beam and the system described in [2] where a preliminary evaluation of the results indicates a maximum acceptable interaction rate of about 20kHz.

One suggestion [10] to eliminate or reduce the slow component is to include small amounts of additional rare earth ions in the glass such as Yb, Tm or Nd. These radiate at long wavelengths, beyond the range of photocathode sensitivity. It has been demonstrated [11] that when equal concentrations of Ce, Nd and Yb were present in a glass similar to GS1 the decay time was greatly reduced. This idea has not been pursued as it would result in a reduction of what is already a barely sufficient light output and we prefer first to investigate the potential afforded by the development of plastic based scintillators which emit light localised within 10 μ m of the ionization source. This can be achieved using conventional plastic scintillators with higher than normal concentrations of wavelength shifter: using a wavelength shifter such as PMP[12] whose absorption and emission spectra are well separated, allows the use of high concentrations with low self-absorption.

A further advantage of plastic scintillator is demonstrated by our measurements of light yield from highly ionizing particles. When used as an

active target the emitted light due to the fragments from the nuclear break-up is undesirably intense and tends to obscure track images close to the interaction. The saturation observed in NE102A is much higher than in GS1 glass and this is expected to improve the clarity of the image.

We have recently exposed fibre bundles, constructed from various plastic scintillators, to a particle beam and will report subsequently.

Acknowledgements

We thank C.G.Hill of Levy-Hill Laboratories for providing the annealed GS1 samples, and for his interest and help in this study. We also acknowledge assistance from G.Hall of Imperial College with the α -source measurements and J.Dupont and J.Dupraz of the CERN EF Instrumentation group for their technical help.

References

- [1] For a review of this field see:
J.Kirkby. Workshop on vertex detectors: State of the Art and Perspective. Erice, Sicily, 21-26 September 1986.CERN EP/87-60
A.Bross, et al: Proceedings of the workshop on New Solid State Devices for High Energy Physics, Lawrence Berkeley Laboratory, October 28-30 1985.
- [2] W.Beusch, et al: CERN/SPSC 87-2. P226 (January 1987).
C.Angelini, et al: Proceedings of the 3rd Topical Seminar on Perspectives for Experiments at Future High Energy Machines and Underground Laboratories, San Miniato, March 1988: CERN EP/88-110. (to appear in Nucl. Instr. and Meth.)
- [3] R.Ruchti, et al: IEEE Trans. on Nucl. Sc. NS-31 (1984) 69.,NS-32 (1985) 590.
A.Rogers, et al: IEEE Trans. on Nucl. Sc. NS-34 (1987) 541.
- [4] M.Atkinson, et al: Nucl. Instr. and Meth. A254 (1987) 500.
- [5] R.Ruchti, et al: IEEE Trans. on Nucl. Sc. NS-33 (1986) 151.
- [6] E.A.Yates, et al: EG&G technical note S-60-TN. EGG1183-2104 (1966).
- [7] Photomultiplier Manual: RCA Technical Series, PT-61 (1970) p.47.
- [8] G.Bertolini, et al: Nucl. Instr. and Meth. 7 (1960) 350.
- [9] E.J.Fairley and A.R.Spewart: Nucl. Instr. and Meth. 150 (1978) 159.
- [10] C.G.Hill: Private Communication.
- [11] S.Gandy, et al: Appl.Phys.Letts. 6 (1965),46.
- [12] P.Destrueel, et al: CERN EF/89-9 (to appear in Nucl. Instr. and Meth.)

Figure Captions

- 1. Set-up used for delayed pulse height analysis of light emission.
- 2. Typical pulse height spectrum obtained from GS1 sample (at a delay of 5 μ s).
- 3. Emission time data from (a) GS1, (b) NE102A and (c) fast LED.
- 4. Emission time data from GS1 with fit to sum of exponential decay times.
- 5. Emission time data from GS1 comparing pulse height and counting methods. Curves corresponding to terms in the overall fit are indicated.
- 6. Comparison of the slow component in the emission of several GS1 samples.
 - (i) GS1/2, GS1/3, GS1/4 contain 2, 3, 4% Ce₂O₃ by weight.
 - (ii) GS1/4a, GS1/4b were annealed to 600°C and 650°C.
- 7. Cumulative distribution of light emission time from GS1.

Fig. 1

Fig. 2

Fig.3

Fig.4

Delay curves for GS1 samples

Fig.6

GS1 Delay curve

Fig. 5

Fig. 7