DEDICATED SCINTILLATING CRYSTALS FOR NEUTRINO AND DARK MATTER DETECTION

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Abstract

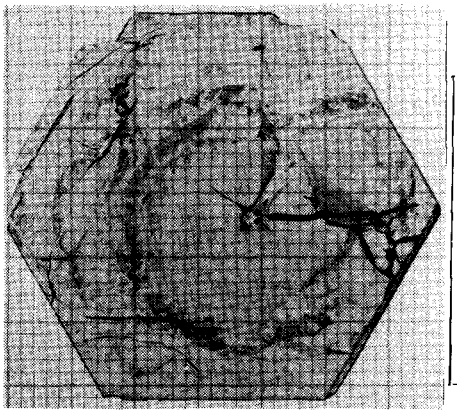
It was recently proposed [1] to use scintillating crystals incorporating a large amount of ^{115}In for the detection of low-energy solar neutrinos through Raghavan's reaction [2]. We report here on recent progress in feasibility studies, i.e. crystal growth of transparent undoped and doped single crystals of indium compounds.

We also discuss some aspects related to the luminescence of scintillators at low temperature, in connnection with the proposal [3] to develop a luminescent bolometer for particle identification through the heat/light ratio.

1 INDIUM BORATE

The original choice of $InBO_3$ [1] was motivated by the previous existence of transparent crystals [4] and the high performance of $InBO_3 : Tb^{3+}$ and $InBO_3 : Eu^{3+}$ powder as a luminophore (although the fluorescence decay time of such dopants is too slow for our purposes). $InBO_3$ and $InBO_3 : Tb^{3+}$ single crystals (Fig.1) were grown by spontaneous nucleation during slow cooling [5] of high temperature solutions using $LiBO_2$ as a solvent. Other luminescent compounds incorporating indium can be dealt with by similar technques. Good optical properties were the first goal. Subsequently, luminescence of $InBO_3 : Tb^{3+}$ single crystals was checked (Fig.2) and found to be very intense. Doping with Ce^{3+} (τ, fluorescence decay time, = 25-60 ns) is presently under investigation. This choice is dictated by the high time resolution required for neutrino detection through Raghavan's reaction (better than 100 ns). However, Ce^{3+} doping of $InBO_3$ poses serious chemical challenges [6] and most likely requires a departure from the initial $InBO_3$ matrix (for instance, by replacing part of the indium by a rare earth that can be cerium-doped).

Fluorides may be another possibility, as CeF_3 is a recently proposed fast scintillator [7]. Assuming that a fast indium scintillator can be obtained, light yield and energy resolution will remain a crucial issue for background rejection. Detector architecture also requires a careful study, including the possible use of read-out devices other than photomultipliers.



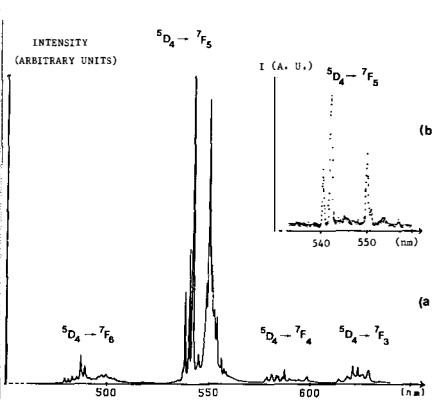


Fig. 1 (left) - Transparent single $InBO_3$ crystal grown by the flux method.

Fig. 2 (right) - Emission spectrum of $InBO_3 : Tb^{3+}$ when excited with 2925 Å ultraviolet light at room temperature.

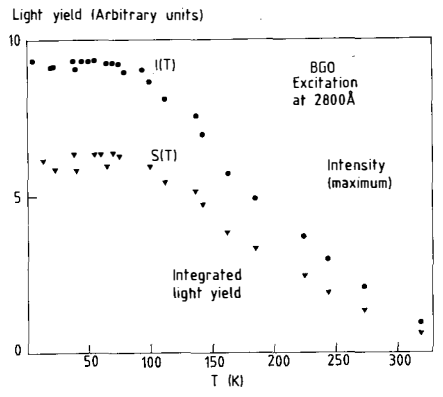
2 TOWARDS A LUMINESCENT BOLOMETER?

Dark matter searches through nucleus recoil are known to face a severe background [8] due to radioactivity from inside the detector. Although present technology allows to obtain extremely high purity rates for germanium, it is not obvious to what extent the same

performance can be obtained for other materials. For energy deposition above 1 keV (at which the best scintillators still provide a sizeable light yield), it may be possible to achieve particle identification by simultaneously measuring the produced light and heat, using a high performance scintillator cooled to very low temperature. A substantial improvement in background rejection would then be achieved through the heat/light ratio, where a nucleus recoil is expected to produce less light than a low energy β or γ.

Some intrinsic scintillators produce a very high light yield when cooled down to ^4He temperatures [9]. Although further studies, down to 50 mK, are required, in the commonly used models the light yield is expected to remain stable between 4K and bolometric temperature, and so does the fluorescence decay time. At temperatures below 100 K, BGO reaches a scintillation efficiency equal to that of NaI:Tl at room temperature (Fig. 3a), whereas the fluorescence decay time at 4K becomes of the order of 200 μs (Fig. 3b).

A potential advantage of cooled BGO over room temperature NaI:Tl would be energy resolution from intrinsic scintillation, where luminescence is free from fluctuations due to irregularities in dopant distribution. At very low temperature, energy resolution would be further improved by compensation between optical and thermal signals. Since the scintillation signal is faster, it can be used to improve timing information.



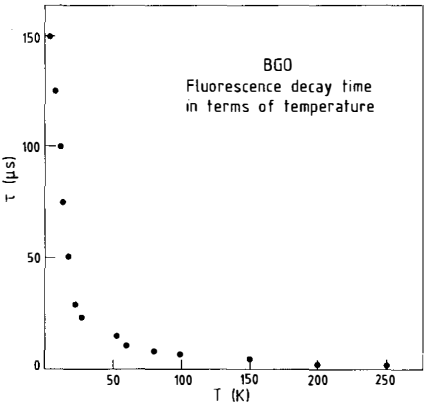
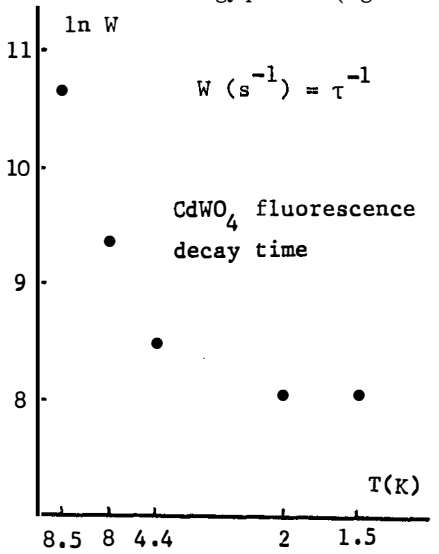


Fig. 3a (left) - Temperature dependence of BGO light yield under ultra-violet excitation, according to [9].

Fig. 3b (right) - Temperature dependence of BGO fluorescence decay time, from the same reference.

We have recently measured the fluorescence decay time of $CdWO_4$ (which again produces a high light output at low temperature), down to 1.5 K. The measurements suggest the value $\tau = 200\mu s$ in the low T limit (Fig. 4). W nucleus has good spin properties for galactic photino detection [10]. Finally, there are indications [11] that Ce^{3+} decay time remains as fast at 60 ns at cryogenic temperatures (close to its room temperature value). The luminescent bolometer would then be made of a transparent scintillating crystal with a composite read-out: a) a cryogenic photosensitive device (semiconductor, superconductor

or a thin black bolometer layer) coupled to one of the faces, the other faces being painted or treated so as to prevent light from escaping; b) a thermistor implanted on one of the treated faces in order to detect the thermal pulse (Fig. 5). Although many technical difficulties are expected, this may be a most promising development in the field of cryogenic detectors for low energy particles (e.g. dark matter searches).



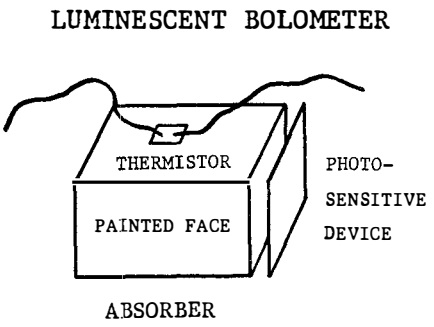


Fig. 4 (left) - Fluorescence decay time of $CdWO_4$ at 500 nm emission wavelength and 2935 Å excitation wavelength, in terms of temperature between 8.5 K and 1.5 K .

Fig. 5 (right) - A naive picture of the foreseen "luminescent bolometer".

References

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