Study of Scintillation Detectors for Direct Dark Matter Search Experiment

S. Ghosh[1],* P. Bhattacharjee[1], S. Bhattacharya[1], D. Das[1], M. Das[1], C. C. Dey[1], S. C. Gadkari[3], B. Karmakar[1], Meghna K K[2], D. Majumdar[1], P. Majumdar[1], N. K. Mondal[1], S. Saha[1], S. Sen[3], S. Seth[1], M. K. Sharan[1], and M. Tyagi[3]
[1] *Saha Institute of Nuclear Physics, HBNI, Kolkata-700064, West Bengal, INDIA*
[2] *National Institute of Science Education and Research,*
HBNI, Jatni 752050, Odisha, INDIA and
[3] *Technical Physics Division, Bhabha Atomic Research Centre, Mumbai-400 085, INDIA*

Introduction

Observational evidence about the Universe has substantiated that normal baryonic matter only constitutes about 5% [1] of the total mass-energy content of the Universe. A significant portion of the mass-energy content is constituted by invisible and non-relativistic Dark Matter. The identity of Dark Matter is still not known and one possible candidate is the Weakly Interacting Massive Particles (WIMPs). WIMPs occur naturally in Beyond Standard Model theories of Particle Physics which take into account supersymmetric extensions to the Standard Model.

By hypothesis, WIMPs can interact only via gravitational interactions and thus, WIMPs can directly be detected only by searching for nuclear recoils produced by elastic collisions between the WIMPs and the nuclei of the detector material. The detection involves using highly sensitive and low background detectors since the event rates are expected to be of the order of 0.1 events/kg/day or even less.

Detection Techniques

The nuclear recoils produced due to elastic collision with WIMPs, as shown in FIG. 1, deposits an energy into the detector medium, which can manifest itself in different ways such as scintillation, phonon generation, and ionization. Most experiments use any two of the above techniques simultaneously for better discrimination against electron recoil events.

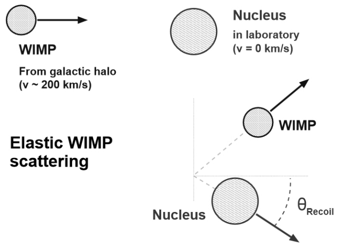

FIG. 1: Diagram of WIMP-Nucleus elastic collision in Laboratory Frame.

The proposed dark matter search experiment at INO (DINO) will attempt to detect both the scintillation as well as ballistic phonon signals from the nuclear recoil caused by WIMPs.

For phonon detection sensitivity, we need to go to lower temperatures, of the order of mili-Kelvin, to make the ballistic phonon detection possible. The light output of scintillators, doped and intrinsic, are known to have a temperature dependence. The desirable feature which would dictate the choice of the scintillator to be used is increased light output with the decrease in temperature. We studied four scintillators, Cerium-doped GGAG ($Gd_3Ga_3Al_2O_{12}$), intrinsic GGAG, intrinsic CsI and intrinsic $ZnWO_4$. All of these scintillators were manufactured at the Crystal Growth Facility of BARC, Mumbai.

Experimental Set Up

We studied the variation of light output of the scintillators mentioned above as a function of temperature. The Photon read-out used

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*Electronic address: `sayan.ghosh@saha.ac.in`

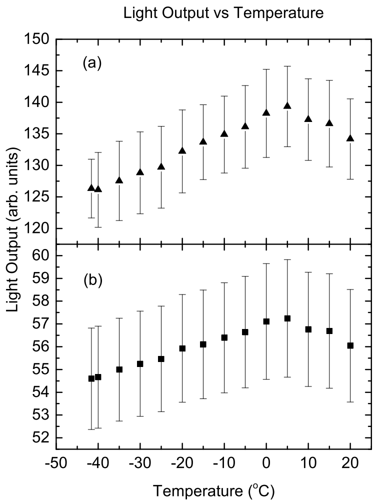

FIG. 2: Light Output variation as function of temperature for Ce-doped GGAG for (a)356 keV and (b)31 keV lines of Ba^{133} source. The uncertainties are the FWHMs as obtained from Gaussian fit.

was Silicon Photomultiplier (SiPM) available from M/s SenSL, which is optimized for rare event searches. The experiment was done by setting up a cooling chamber using a two-stage Peltier Cooler. We attained temperatures of $-15°$C using this setup. We also used a freeze dryer based cooling system to go down in steps to $-40°$C. The light output variation for the Ce-doped GGAG scintillator was done by observing the MCA output channel shift of the 31 keV and 356 keV γ rays from Ba^{133} source. The photopeaks are not produced in the γ-ray spectra for the intrinsic crystals and therefore, the variation of the Compton edges corresponding to the 356 keV γ rays was studied as a function of temperature.

Results

The light output variation of Ce-doped GGAG as a function of temperature is shown in FIG. 2. It shows that initially for both the 31 keV and 356 keV lines, there is an increase in light output and a maximum is reached near 5°C. On further decrease of temperature, the light output decreases significantly as the temperature is lowered till $-41.6°$C.

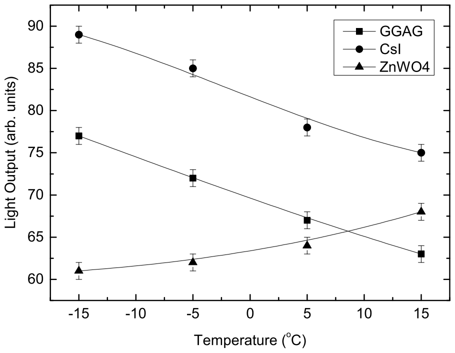

FIG. 3: Light Output variation as function of temperature for intrinsic scintillators

The temperature dependence of light output of the intrinsic scintillators shows a completely different behavior as shown in FIG. 3. The light output of intrinsic CsI and GGAG increase significantly with decreasing temperature whereas, on the other hand, for Zinc Tungstate, the light output shows a decreasing trend with decreasing temperature. However, the rate of decrease of light output, in this case, shows a tendency to plateau at decreasing temperatures beyond $-15°$C.

Conclusion

The light output of the intrinsic scintillation materials studied in this work shows increasing trend at lower temperatures. This behavior is well studied for intrinsic CsI to lower temperatures [2], which is in agreement with the trend observed in this work. The existence of two emission components with different scintillation decay time appears to be a distinct possibility in these scintillators which may be utilized for pulse shape discrimination in future. Extension of this study to lower temperatures down to ∼10 K is in progress.

References

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