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DSB:Ce^{3+} scintillation glass for future

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Abstract. One of the main challenges for detectors at future high-energy collider experiments is the high precision measurement of hadron and jet energy and momentum. One possibility to achieve this is the dual-readout technique, which allows recording simultaneously scintillation and Cherenkov light in an active medium in order to extract the electromagnetic fraction of the total shower energy on an event-by-event basis. Making use of this approach in the high luminosity LHC, however, puts stringent requirements on the active materials in terms of radiation hardness. Consequently, the R&D carried out on suitable scintillating materials focuses on the detector performance as well as on radiation tolerance. Among the different scintillating materials under study, scintillating glasses can be a suitable solution due to their relatively simple and cost effective production. Recently a new type of inorganic scintillating glass: Cerium doped DSB has been developed by Radiation Instruments and New Components LLC in Minsk for oil logging industry. This material can be produced either in form of bulk or fiber shape with diameter 0.3-2mm and length up to 2000 mm. It is obtained by standard glass production technology at temperature 1400ºC with successive thermal annealing treatment at relatively low temperature. The production of large quantities is relatively easy and the production costs are significantly lower compared to crystal fibers. Therefore, this material is considered as an alternative and complementary solution to crystal fibers in view of a production at industrial scale, as required for a large dual readout calorimeter. In this paper, the first results on optical, scintillation properties as well as the radiation damage behaviour obtained on different samples made with different raw materials and various cerium concentrations will be presented.

1. Introduction

In future high energy experiments at new particle colliders, the precise measurement of the jets and hadrons will be one of the main challenges. The dual readout technique is one of the approaches,

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which allows the improvement of the hadronic energy resolution by measuring the electromagnetic fraction of the hadronic shower on an event-by-event basis [1]. This can be obtained by detecting simultaneously scintillation and Cerenkov signal produced in an active medium. In High Luminosity LHC (HL-LHC), the operational conditions in a high dose rate irradiation environment add a stringent requirement in terms of radiation hardness for the active material and therefore require search for new radiation tolerant materials. Among the different scintillating materials, scintillating glasses, despite their relatively simple and cost effective production, have, up to now, not been widely used in high energy experiments due to their poor radiation hardness and low light yield. The main cause of the low radiation tolerance of usual scintillating glasses is their amorphous structure. The "non-organized" structure of the atoms allows presences of structural defects, which favor the creation of colors center under irradiation.

In the case of binary systems based on SiO_2, the lattice structure is formed by layers of tetrahedral Si with metallic ions between them. Therefore monovalent or bivalent metallic ions can easily be replaced by bivalent or trivalent rare earth ions. In the last case, charge compensation occurs by reordering of cation systems. For instance, three divalent ions are replaced by two trivalent species. The disilicate of barium (BaO_2-SiO_2) doped with Ce (DSB:Ce) is one of the new scintillation materials made from binary composition and obtained by standard glass production technology with a successive thermal annealing. In this paper, we discuss the optical quality of DSB based on measurements performed on a first set of samples.

2. DSB production and properties

DSB is produced from a mixture of BaO_2 and SiO_2 by standard glass production technology at a temperature of 1400°C. The obtained glass is then thermally annealed at relatively low temperature (<1000°C) to achieve its nanostructure. It can be produced either in form of bulk or fiber shape with diameters of 0.3-2mm and lengths up to 2m as can be seen in Fig. 1.

As opposed to common heavy inorganic scintillators, DSB glass has a slightly lower stopping power. Its density is 3.8 g/cm^3, its effective Z is 51 and its radiation length (X_0) is 3.3 cm. Therefore applications of DSB in calorimetry will most probably require an additional absorber. On the other hand, on the contrary to crystalline materials, the production of large quantities is relatively easy and the production costs are rather low.

Figure 1: Picture of DSB glass in bulk and fiber shapes.

3. DSB:Ce samples

For the present study, five samples of bulk DSB glass material with different Cerium concentration were investigated (reference number #2743-2747). Samples #2743-2745 and #2746,2747 were produced from two different types of raw material purity. The Cerium concentration and raw material is provided together with a picture in Fig. 2.

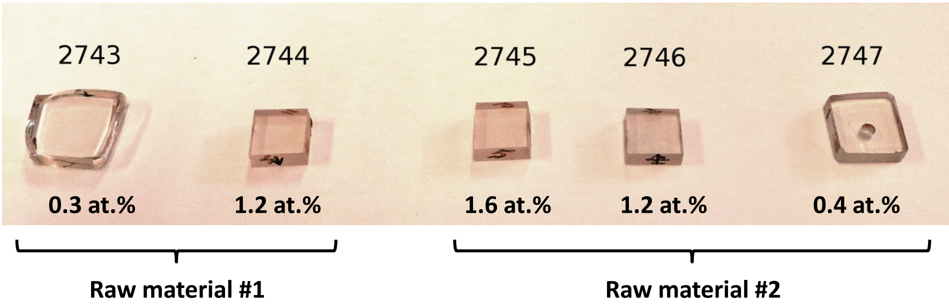

Figure 2: Picture of the five DSB samples studied here, with their respective Cerium concentration and raw material origin.

4. Measurements of the optical properties

A typical transmission spectra of DSB:Ce is shown in Fig. 3. It is characterized by an absorption edge around 365nm corresponding to the Cerium absorption band and a transmission above 80% at higher wavelengths. In Fig. 4, the excitation and emission spectra measured by photoluminescence at room temperature are shown. For these measurements, we selected the sample with the lowest Cerium concentration (#2743). The excitation spectrum (measured at an emission wavelength of 425 nm) is characterized by two peaks at 280 nm and 350 nm, due to the 5f-4d Ce^{3+} transition. The emission spectrum (measured at an excitation wavelength of 300 nm) is peaking at 425nm. It is noteworthy that the position of this peak depends on the concentration of Ce, as shown in Fig. 5.

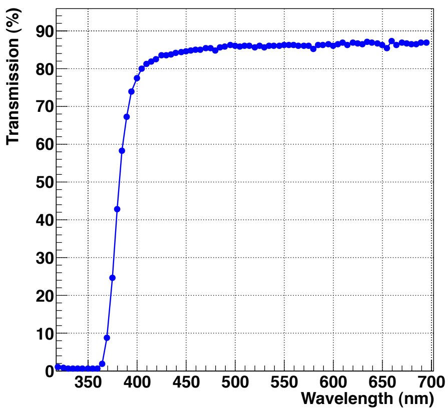

Figure 3: Optical transmission of DSB sample.

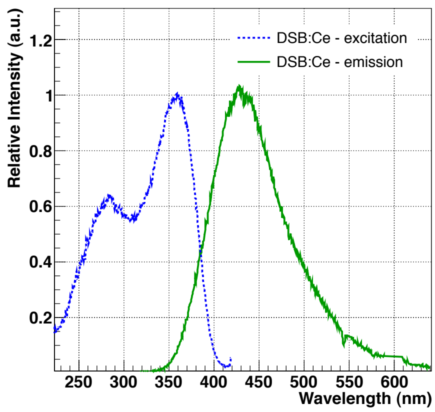

Figure 4: Excitation and emission spectra of DSB.

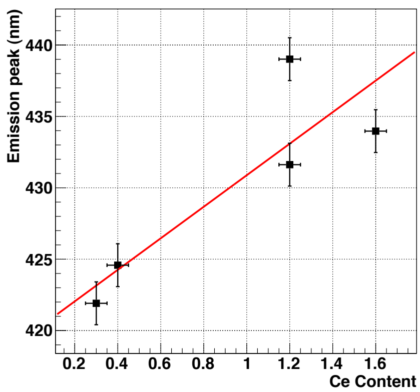

Figure 5: Correlation between position of peak emission and cerium concentration.

5. Measurements of the scintillation properties

All the samples show a very similar scintillation decay constants. Fig. 6 shows the scintillation decay time spectra of one of the DSB sample, measured at room temperature. The decay time is well approximated using a sum of three exponentials. The pulse shape is dominated by a fast 30-ns decay (~40% of total weight) and a slightly slower component (~50% of total weight) around 180 ns. The presence of this slower component in the scintillation depends both on Ce concentration and Ba/Si ratio in a final composition. It is noteworthy that ~74% of the light is contained in the first 100ns. Such a time response is compatible with high repetition rates, as those considered for HL-LHC. For what concerns the very fast component, the role of the instrumental response cannot here be completely excluded.

The light output of one of the DSB sample (volume ~ 1cm^3) was measured with γ-rays of 59.9 keV and 662 keV generated by respectively an ^{241}Am and a ^{137}Cs radioactive source. The obtained light output spectrum is presented on Fig 7. We estimate the light output to be around 100pe/MeV, thus five times larger than the one of a PWO crystal at room temperature [3]. We also investigated the temperature dependence of the light output from -25 to +25 °C. The temperature coefficient was found to be less that 0.04%/°C [3].

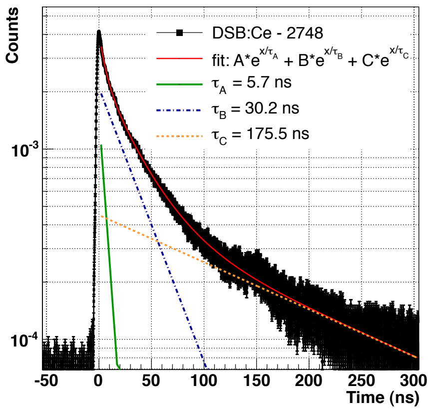

Figure 6: Typical decay time spectrum of DSB and its decomposition in three decay components.

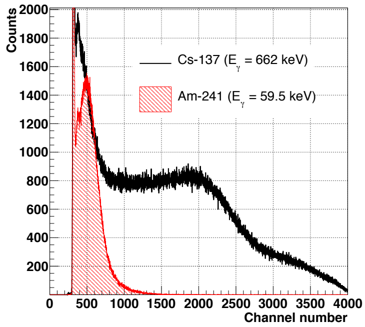

Figure 7: Light output spectrum obtained with γ-rays of 59.6 keV and 662 keV.

6. Preliminary measurements of the radiation hardness

First irradiation tests have been performed on DSB samples with gamma irradiation at a dose rate of 500Gy/h and a total dose of 1000Gy. Figure 10 shows the comparison of the induced absorption for two samples produced with two different types of raw material. A factor two in the damage intensity is observed between the two samples. These preliminary results indicate that by optimizing the raw material purity and the production parameter improvement of radiation damage could be obtained. Further optimization of raw material and production conditions are currently investigated.

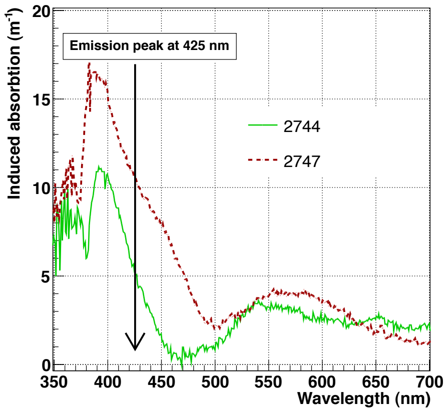

Figure 9: Comparison of induced absorption after 1000Gy irradiation (Co^{60}), on two DSB samples produced with two different raw materials.

7. Conclusions

DSB:Ce scintillating glass has been investigated for the first time. DSB is characterized by an emission at 440nm, which is well matching the sensitivity of the commonly used photodetectors like PMT, VPT, SiPM and APD. Moreover, DSB:Ce has a very small temperature dependence of the light output: 0.05 %/°C, thus about 40 times less than the one of PWO [3]. Therefore in the range of -20-+50ºC no complex cooling system with be necessary to operate a detector built with DSB:Ce. Material. Undoped DSB will be a Cherenkov radiator.

The production of large quantities is relatively easy and the production costs are significantly lower compared to crystal fibers. Therefore, this material is considered as an alternative and complementary solution to crystal fibers in view of a production at industrial scale, as required for a large dual readout calorimeter. The possibility to produce also DSB in fiber shape at a rate of 2cm/s allows the production of large quantities of fibres relatively easily and a production cost significantly lower compared to crystal fibers. Therefore, this material is considered as an alternative and complementary solution to crystal fibers in view of a production at industrial scale, as required for a large dual readout calorimeter.

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