Improvement of Scintillation Performance in Large Size Yttrium Doped BaF_2 Crystals

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***Abstract*–Barium fluoride (BaF_2) crystal with sub nanosecond scintillation has attracted a broad interest in the HEP community. One crucial issue is its slow scintillation component with 600 ns decay time, which causes pile-up. Our previous studies show that the slow component can be suppressed effectively by yttrium doping. In this work, a 160 mm long BaF_2 ingot with 5% yttrium doping was grown at BGRI, and was used to cut a 100 mm crystal and several small samples. Their optical and scintillation properties were measured at Caltech. The results confirm that yttrium doping effectively suppresses the slow component while maintaining its ultrafast light and light response uniformity unchanged. This is encouraging for a BaF_2:Y crystal based ultrafast calorimeter for Mu2e-II.**

I. INTRODUCTION

BECAUSE of its ultrafast scintillation component peaked at 220 nm with sub nanosecond decay time and excellent radiation hardness, BaF_2 crystals have attracted a broad interest in the high energy physics community. It is the baseline option for the Mu2e-II calorimeter [1] to face the challenge of the expected high event rate and severe ration environment [2]. BaF_2, however, is well known having a slow scintillation component peaked at 300 nm with 600 ns decay time and five times intensity of the ultrafast component, which causes serious pile-up. Two effective approaches were used to handle the slow component. 1) Using solar blind photodetector to selectively read out the fast component but not the slow [3]; and 2) doping BaF_2 with rare earth to suppress the slow. It was shown that the slow can be suppressed effectively by yttrium doping [4, 5]. The fast/slow (F/S) ratio and light response uniformity (LRU) of the 1st 190 mm long crystal grown at Shanghai Institute of Ceramics (SIC), however, was not good enough because of its poor optical quality and not optimized yttrium doping.

In this investigation, we present optical and scintillation performances for a 100 mm long BaF_2:Y crystal grown at Beijing Glass Research Institute (BGRI). Its optical and scintillation properties were measured in Caltech HEP Crystal Laboratory. Application and plan for BaF_2:Y investigation are also discussed.

II. SAMPLES AND EXPERIMENTAL DETAILS

Fig. 1 shows a photo for a BaF_2:Y crystal of 25×25×100 mm^3 with all six surfaces polished (top), and its location in an ingot of Φ40×160 mm^3 grown at BGRI with 5at% Y-doping (bottom). Transmittance was measured by using a PerkinElmer Lambda 950 spectrophotometer with 0.15% precision. Light output was measured by using a Hamamatsu R2059 PMT with a grease coupling and 0.511 MeV γ-rays from a ^{22}Na source with a coincidence trigger.

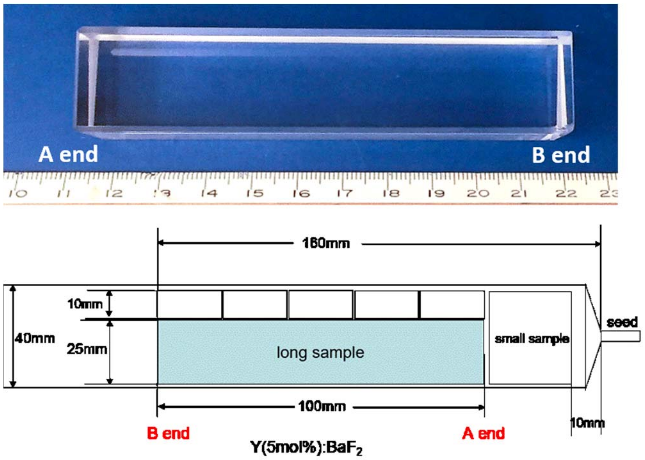

Fig. 1. A photo showing BaF_2:Y crystal of 25×25×100 mm^3 (top) and a schematic showing its location in the ingot of Φ40×160 mm^3 grown at BGRI with 5at% Y-doping (bottom).

III. RESULTS AND DISCUSSION

Figs. 2 and 3 show longitudinal and transverse transmittance spectra along 100 mm and 25 mm light path respectively for the BaF_2:Y sample of 25×25×100 mm^3 together with its emission spectrum. The absorption bands peaked at 230, 260, and 290 nm may be attributed to Ce^{3+} contamination. Further improvement of transmittance in the ultraviolet range is needed. Also shown in Fig. 3 are the values of emission weighted longitudinal transmittance (EWLT) as a function of the distance to the seed end. Two dips were found at 38 and 75 mm from the seed end. Fig. 5 shows light output as a function of the integration time with the seed (top) and tail (bottom) end coupled to the PMT, the fast (A_0) and slow (A_1) components can be extracted by an exponential fitting. The fast/slow (F/S) ratio is 1.9 and 1.5 respectively at the seed and tail end, which can be compared to typical 0.1~0.2 for undoped BaF_2 crystals,

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confirming that yttrium doping effectively suppresses the slow component and maintains the ultrafast component.

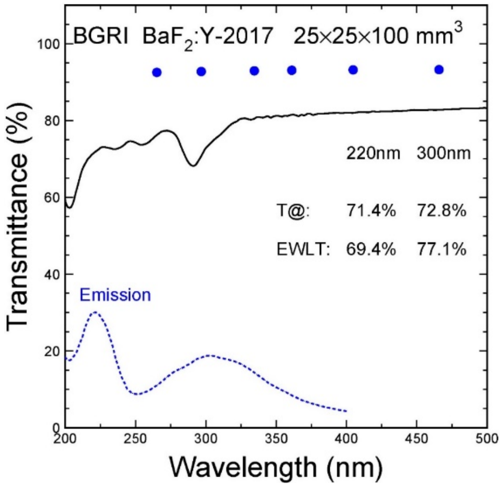

Fig. 2. Longitudinal transmittance spectra along 100 mm path for the BaF$_2$:Y sample of 25×25×100 mm^3.

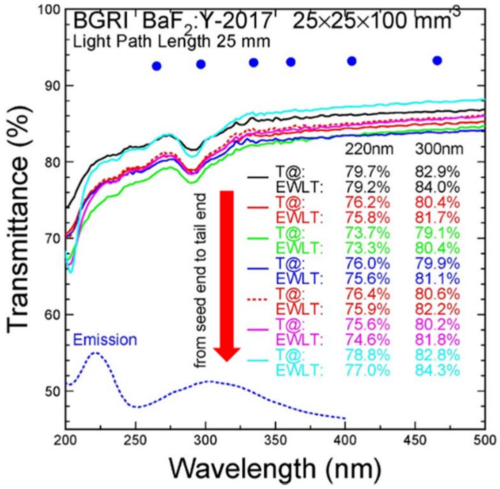

Fig. 3. Transverse transmittance spectra along 25 mm path for the BaF$_2$:Y sample of 25×25×100 mm^3.

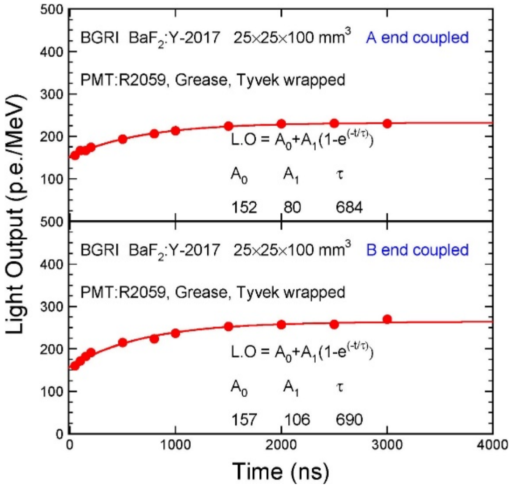

Fig. 4 Light output as a function of the integration time is shown for the seed (top) and tail (bottom) end coupled to the PMT.

Fig. 5 shows light response uniformity measured with 50 (top) and 2,500 ns (middle) integration time as well as their ratio (bottom) for the 100 mm long BaF$_2$:Y sample. The rms (root mean square) of the light output values with 50 ns integration time is about 12%, which is consistent with that observed in un-doped BaF$_2$ crystals.

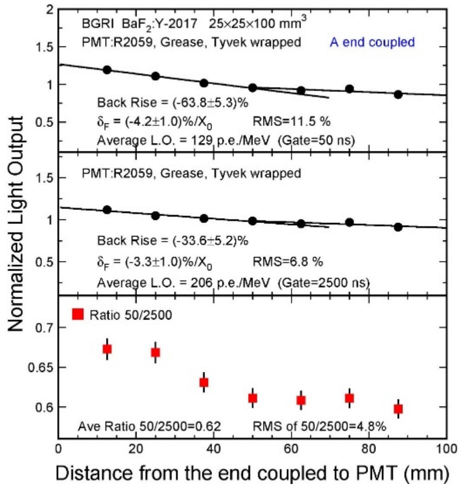

Fig. 5. Light output measured with 50 (top) and 2,500 (middle) ns gate and their ratio (bottom) are shown as a function of distance to the seed end coupled to the PMT for the 10 cm long BaF$_2$:Y sample.

IV. SUMMARY

A 100 mm long BaF$_2$ crystal with 5% yttrium doping grown at BGRI was investigated. The result confirms our early observation that its slow component is suppressed greatly by yttrium doping. Compared to our previous result for a 19 cm long BaF$_2$:Y grown at SIC, a better F/S ratio and light response uniformity were observed for this BaF$_2$:Y crystal.

BaF$_2$:Y crystals with suppressed slow component are important for applications where ultrafast timing is required, such as the proposed CMS MTD at CERN, the Mu2e-II calorimeter at Fermilab and gigahertz (GHz) hard X-ray imaging for the proposed Marie project at LANL. Our investigations will continue to improve optical quality of large size BaF$_2$:Y crystals for Mu2e-II, and to understand its radiation hardness against γ-rays and hadrons.

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