Crystal and Photosensor Development for a Fast BaF_2 Electromagnetic Calorimeter

Letter of Interest for Snowmass 2021

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Abstract

Next generation experiments will require high resolution crystal calorimeters with improved timing, rate capability and radiation hardness. Barium fluoride (BaF_2) crystals, which have an ultrafast scintillation component with a decay time of 0.6 ns at a wavelength of 220 nm have therefore attracted broad interest in communities pursuing ultrafast detectors for future HEP experiments or GHz hard X-ray imaging for XFEL facilities. In order to take full advantage of the fast scintillation component, it is important to suppress signals from the larger slow scintillation component at 300 nm. This can be done by doping the crystals to suppress the slow component and/or by using a photosensor with good quantum efficiency for the fast component and lower efficiency for the slow component. We have been pursuing both these avenues and have achieved some measure of success. Continued R&D efforts over the next several years will be required to bring a barium fluoride calorimeter system to a mature state for inclusion in next generation experiments.

Because of its ultrafast scintillation peaked at 220 nm with less than 0.6 ns decay time, barium fluoride (BaF_2) crystals have attracted broad interest in communities pursuing ultrafast calorimetry for future high energy physics and nuclear physics experiments and GHz hard x-ray imaging for future X-ray Free Electron Laser (XFEL) facilities. One crucial problem in utilizing the BaF_2 fast component is its slow scintillation peaked at 300 nm with a 600 ns decay time and five times the intensity of the fast component, which results in pileup and noise in an ultrafast environment. Our R&D effort has employed two approaches to suppress the slow component: selective doping of BaF_2 [1] [2] [3], and development of a solar-blind UV photodetector with good quantum efficiency to the fast component but insensitive to the slow component [4] [5].

Figure 1 shows x-ray excited emission spectra for five yttrium doped BaF_2 crystals (BaF_2:Y), showing the effective suppression of the slow component by optimizing the Y doping level. This doping procedure produces a strong suppression of the slow component with only a small reduction in the fast component. This is quite an encouraging result, but further effort is needed to refine doping procedures to produce uniform results along the length of a long crystal and to understand the performance of the doped crystals at the high electromagnetic and neutron irradiation levels expected in next-generation experiments.

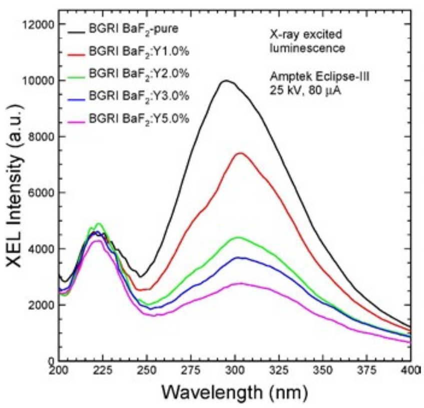

Figure 1. Barium fluoride emission spectra for various yttrium doping levels.

There are several potential candidates for photosensors that can exploit the BaF_2 fast scintillation component. Such a sensor must be fast, have good quantum efficiency at 220 nm and substantially reduced efficiency at 300 nm, work in a ~1T axial magnetic field and be radiation hard. Candidates include various types of microchannel plate photomultipliers with solar-blind photocathodes and solid state devices such as SiPMs with solar blind response or integrated and/or interposed bandpass filters

We have been pursuing the development of SiPMs that have integrated atomic-layer-deposition (ALD) bandpass filters, with the goal of producing back-side illuminated delta doped devices with excellent quantum efficiency at 220 nm, strong rejection of 300 nm response, time response superior to existing SiPMs and adequate longevity in the face of exposure to strong UV radiation.

The initial devices produced in collaboration with FBK and JPL are 6 x 6 mm front-illuminated SiPMs with a three-layer ALD filter. The absolute quantum efficiency as a function of wavelength has been measured with a spectrophotometer down to 200 nm with QE/PDE calculated using a pulsed blue LED at 465 nm, normalizing to a NIST traceable reference silicon photodiode.

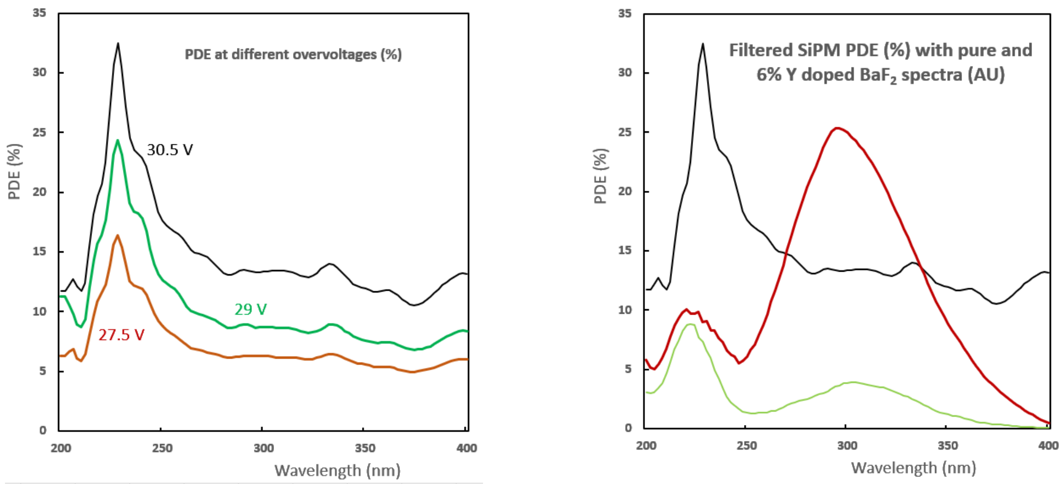

Figure 2. a) Measured photon detection efficiency (PDE) as a function of wavelength for FBK SiPM 612 with three-layer filter at three bias voltages. b) PDE at 30.5 volt bias compared to BaF_2 scintillation spectrum for undoped BaF_2 and doped with 6% yttrium.

Figure 2a) shows the PDE of SiPM 612, measured with overvoltages of 2.5, 4 and 5.5 V. Figure 2b) compares the PDE at a bias of 30.5 volts to the barium fluoride scintillation spectrum for pure and 6% Y-doped crystals. Figure 3 show the measured response of a 1” BaF_2 crystal read out by the filtered SiPM to cosmic rays. The peak corresponds to 11 pe/MeV.

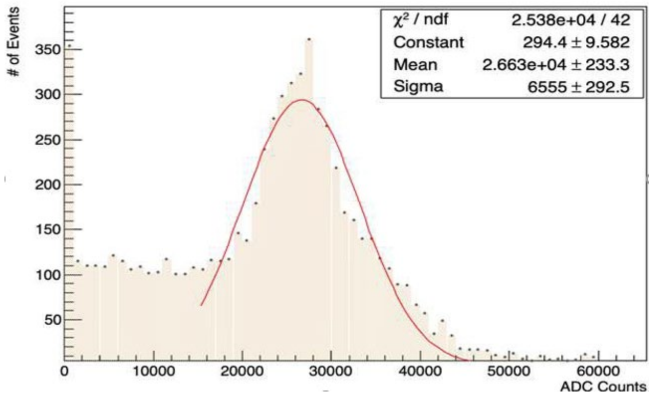

Figure 3. Cosmic ray signal for BaF_2 crystal with filtered SiPM.

The next steps in this R&D effort are to improve the centering and long wavelength rejection with a more sophisticated integrated filter, and to develop backside-illuminated, delta-doped versions of these devices. This will improve the peak PDE, improve the time response of the SiPM and allow the device to survive the intense integrated dose of ultraviolet radiation from the scintillator.

This effort is also a part of the Snowmass 2021 Rare Process and Precision Measurements Topical Group RF5 [6].

References

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