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QE/PDE of VUV Photodetectors for BaF_2 Readout

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***Abstract*–Because of its ultrafast scintillation of less than 0.6 ns decay time barium fluoride (BaF_2) crystals have attracted a broad interest in the communities pursuing ultrafast detectors for future HEP experiments, GHz hard X-ray imaging for future XFEL facilities and medical imaging. A crucial issue of this application is photodetector response down to the VUV range. In this paper, we report quantum efficiency and photon detection efficiency measured for several photodetectors down to 200 nm and their corresponding figures of merit for detecting the ultrafast component and the ability of suppressing the slow component.**

I. Introduction

BECAUSE of its ultrafast scintillation peaked at 220 nm with less than 0.6 ns decay time, barium fluoride (BaF_2) crystals have attracted a broad interest in the communities pursuing ultrafast calorimetry for future high energy physics and nuclear physics experiments, GHz hard x-ray imaging for future X-ray Free Electron Laser (XFEL) facilities and medical imaging. One crucial issue of BaF_2 is its slow scintillation peaked at 300 nm with a 600-ns decay time and an intensity of five times of the fast component, which causes pileup and noise in a high rate environment. R&D has been carried out by taking two approaches to suppress the slow component: 1) selective doping in BaF_2, and 2) development of solar-blind VUV photodetector sensitive to the fast component but not the slow component.

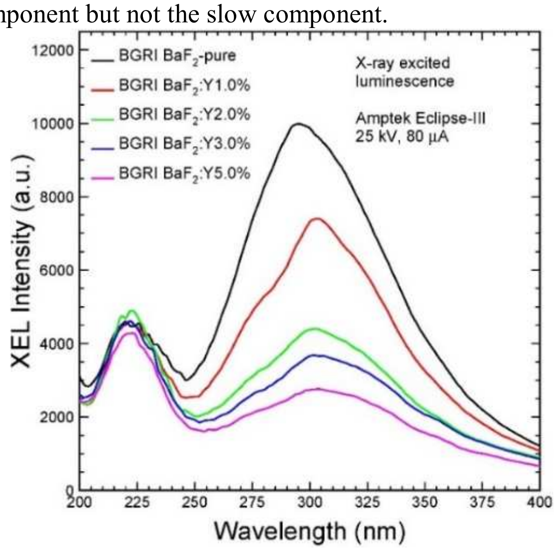

Fig. 1. X-ray excited emission spectra of BaF_2 non-doped and with yttrium doping of 1,0 2.0 3.0 and 5.0 at.%.

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Yttrium doping was found to suppress the slow component significantly while maintaining the ultrafast component as shown in Fig. 1. Selective readout of the ultrafast component, however, is necessary to further suppress the slow component. In this paper, we report quantum efficiency (QE) and photon detection efficiency (PDE) measured for several VUV photodetectors down to 200 nm.

II. Samples and Experimental Setup

Fig. 2 shows a test bench for the QE/PDE measurements as function of wavelength. An UV extended 150 W Xenon lamp is used as the light source. A narrow wavelength band is selected by a monochromator, chopped by an optical chopper and coupled to a 1 mm quartz fiber of NA=0.22. The light pulses of Φ5 mm were aligned to the center of the photodetector to be measured. The photodetector response was scanned down to 200 nm with QE calculated by normalizing to a NIST traceable reference Si-PD (Newport 71650).

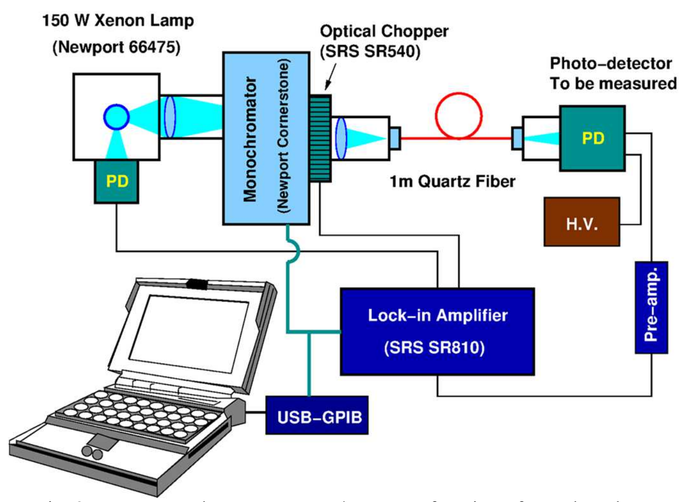

Fig. 2. A setup used to measure QE/PDE as a function of wavelength.

The input photon number was calculated by measuring the DC current and repetition rate of LED pulses with the reference Si-PD with known QE. While QE for PMTs was measured with no gain, PDE for SiPM was measured with a gain. A calibration was carried out by using blue LED pulses at 465 nm of 10 ns FWHM width with the SiPM output pulses integrated and analyzed by a MCA (LeCroy 3001 qvt). The nominal photoelectron (p.e.) number was inferred by a Gaussian fit to the measured photopeak width. The excess noise factor (ENF) of SiPM was estimated as the ratio between the p.e. number from a single p.e. calibration to that from the photopeak width.

III. Results and Discussion

Consistent QE (200-700 nm) was measured for four Hamamatsu R2059 PMTs with a home-mode base to set the gain to one. Fig. 3 shows QE (200-400 nm) of a R2059 and the X-ray excited emission spectra of BaF_2 and BaF_2:Y. Also shown in the figure are the emission weighted QE (EWQE) and the relative light output for the fast and slow components and the fast to slow ratio (F/S) for BaF_2 and BaF_2:Y. The relative light output was estimated by normalizing to the photon number of the BaF_2 fast component. Both the LO_{fast} and F/S are considered as the figures of merit reflecting photodetector's ability for fast detection and slow suppression. They are 15.2% and 1/2.1 for the Hamamatsu R2059.

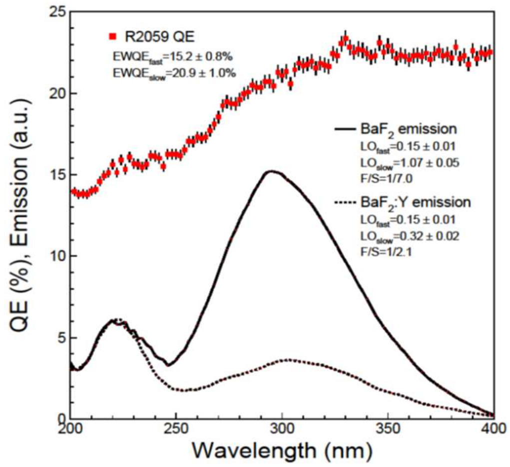

Fig. 3. The measured QE (200-400 nm) of a Hamamatsu R2059 PMT and the X-ray excited emission spectra of BaF_2 and BaF_2:Y.

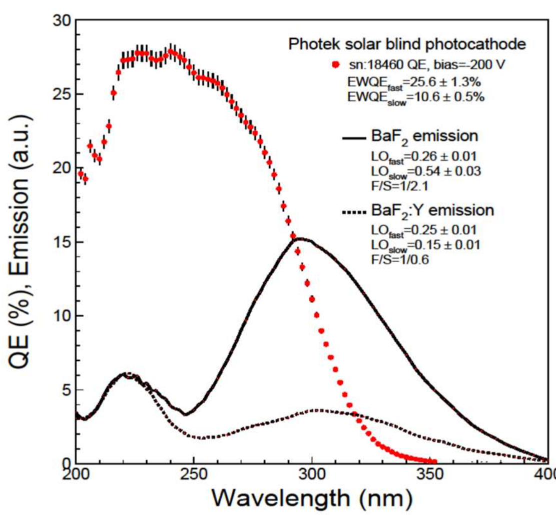

Fig. 4. The measured QE (200-400 nm) of Photek solar blind photocathode and the X-ray excited emission spectra of BaF_2 and BaF_2:Y.

Fig. 4 shows the measured QE (200-400 nm) for a solar blind photocathode from Photek. The EWQE for fast and slow components are 25.6% and 10.6% respectively, showing a clear selective readout for the fast component. While the LO_{fast} is basically the same the fast to slow ratio for BaF_2:Y is about 1/0.6, indicating that solar bind photocathode would be a promising solution. Fig. 5 shows the measured PDE of FBK SiPM integrated with type-I UV bandpass filter. The emission weighted photon detection efficiency (EWPDE) for fast (17.8%) and slow (12.7%) components show a clear selective readout. The corresponding F/S ratio is about 1/1.1, indicating a promising solution as well.

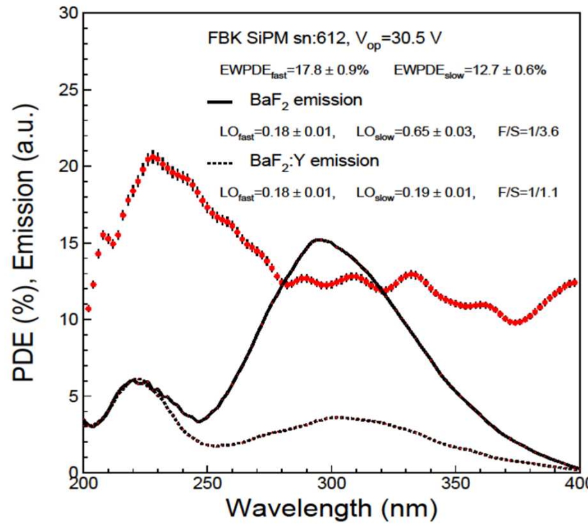

Fig. 5. The measured PDE (200-400 nm) of a FBK SiPM with type-I UV filter and the X-ray excited emission spectra of BaF_2 and BaF_2:Y.

Table I summarized the figures of merit for the VUV photodetectors investigated so far. The first two columns are EWQE and EWPDE for the fast and slow components respectively. The third and fourth ones are the fast/slow ratio for BaF_2 and BaF_2:Y crystals respectively.

Table I. Summary of the figures of merit for VUV photodetectors

Photodetectors	$EWQE_{fast}$ (%)	$EWQE_{slow}$ (%)	BaF_2 F/S	BaF_2:Y F/S
Hamamatsu R2059 PMT	15.2	20.9	1/7.0	1/2.1
Hamamatsu VUV MPPC S13371	10.5	9.8	1/4.8	1/1.5
Photek PMT Solar blind	**25.6**	**10.6**	**1/2.1**	**1/0.6**
FBK SiPM w/UV filter-I	**17.8**	**12.7**	**1/3.6**	**1/1.1**
FBK SiPM w/UV filter-II	20.7	31.5	1/7.8	1/2.4

IV. Summary

While yttrium doping in BaF_2 crystals increases its F/S ratio significantly a solar-blind photodetector is necessary to minimize the pileup for a BaF_2 crystal based ultrafast calorimeter for future experiments, such as Mu2e-II. Progress has been made in solar-blind photocathode and SiPMs with integrated UV band-pass filters. R&D is on-going to further optimize the LO_{fast} and the F/S ratio for BaF_2 crystal readout with VUV photodetectors. We also plan to extend the QE/PDE test bench to 175 nm with N_2 purging.

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