Temporal Response of Fast and Ultrafast Inorganic Scintillators

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***Abstract*–Ultrafast inorganic scintillators with excellent radiation hardness are required for future HEP experiments at the energy and intensity frontiers as well as GHz hard X-ray imaging for the proposed MaRIE project. In this paper, we present an investigation on temporal response of fast and ultrafast inorganic scintillators. Temporal response of BaF_2:Y, BaF_2, YAP:Yb, YAG:Yb, ZnO:Ga, Ga_2O_3, YAP:Ce, LYSO:Ce, LuYAP:Ce, LuAG:Ce, YSO:Ce and GAGG:Ce was measured by ultrafast MCP-PMTs using cosmic rays and 510 keV γ-rays from a Na-22 source at Caltech, and by 30 keV X-ray bunches of 27 and 50 ps length at the Advanced Photon Source facility of Argonne National Laboratory. Their application for future HEP experiments and GHz hard X-ray imaging is discussed.**

***Index Terms*-Crystal, hard X-ray imaging, light output, scintillators, transmittance, ultrafast decay time**

I. Introduction

FAST and ultrafast inorganic scintillators with excellent radiation hardness are demanded by future HEP experiments at the energy and intensity frontiers, such as the HL-LHC [1] and Mu2e-II upgrade [2], and GHz hard X-ray imaging for the proposed MaRIE project [3]. At the Caltech HEP crystal lab we investigated optical and scintillation properties for a set of fast and ultrafast inorganic scintillators [4], including direct-gap semiconductor crystals, such as gallium-doped ZnO (ZnO:Ga), core-valence luminescence crystals, such as BaF_2, and BaF_2:Y, Yb^{3+} activated crystals featured with fast decay time and thermal quenching, such as $YAlO_3$:Yb (YAP:Yb) and $Y_3Al_5O_{12}$:Yb (YAG:Yb), Ga_2O_3 and Ce^{3+} activated bright and fast scintillators, such as lutetium yttrium oxyorthosilicate ($Lu_{2(1-x)}Y_{2x}SiO_5$:Ce or LYSO:Ce) and yttrium oxyorthosilicate (Y_2SiO_5:Ce or YSO:Ce), LuYAP:Ce, LuAG:Ce and GAGG:Ce etc. In this paper, we report their temporal response to pulsed 30 keV x-ray bunches of 27 and 50 ps measured by ultrafast MCP-PMTs at the 10-ID-B beam line of the Advanced Photon Source (APS) facility of Argonne National Laboratory (ANL).

II. Samples and Experimental Setup

Fig. 1 is a photo showing a dozen of inorganic scintillator samples. Fig. 2 shows a schematic of the measurement setup. The experiment was performed at the beamline 10-ID-B running in hybrid fill pattern [5]. A single bunch of 50 ps length is isolated from 8 septuplet bunches by symmetrical 1.594 µs gaps. The 8 groups of septuplet bunches, with a bunch length of 27 ps and a bunch spacing of 2.83 ns, has a periodicity of 68 ns and a gap of 51 ns between groups. The 27 and 50 ps bunch length has a negligible effect to the temporal response.

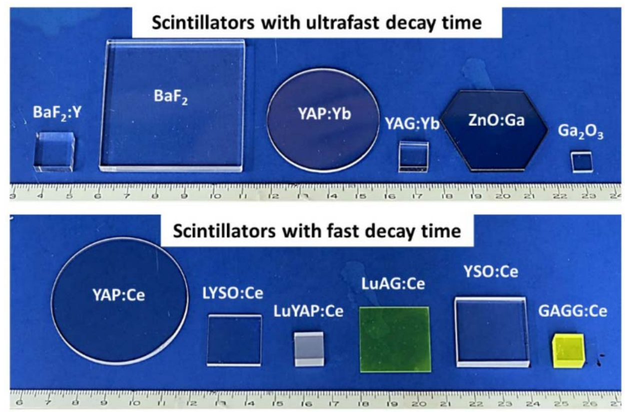

Fig. 1. A photo showing samples investigated in this work.

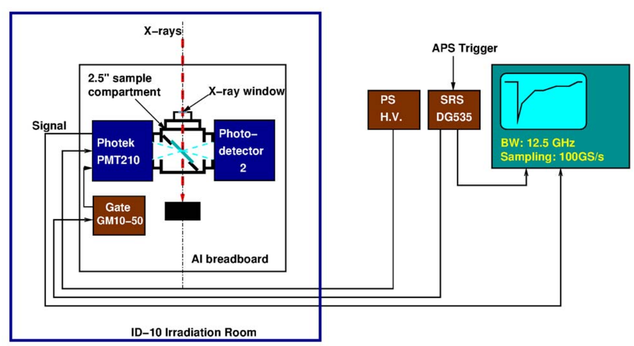

Fig. 2. A schematic showing the setup used in measurements.

Two Photek MCP-PMTs 110 and 210 with a rise time/FWHM of 65/110 ps and 95/170 ps respectively were used to measure the scintillation pulse. A gate unit GM10-50 was used to select measurement window and reduce the trigger rate. The output of the MCP-PMTs was recorded in a Tektronix DPO 71254C (12.5 GHz, 100 GS/s) scope through a 15 m SMA cable.

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III. Experimental Results

BaF_2:Y and BaF_2 show the highest amplitude and fastest response to singlet, which is consistent with the calculated light output in the 1st ns. Fig. 3 shows temporal response of BaF_2:Y (top) and BaF_2 (bottom). The consistent temporal response indicates that yttrium doping does not compromise ultrafast scintillation at 220 nm. Because of the 15 m cable, the measured rise, decay and EWHM width at APS are slightly longer than that measured with a ɣ-ray source at Caltech. Fig. 4 shows that both BaF_2:Y and BaF_2 are able to distinguish the seven bunches in septuplet with a bunch spacing of 2.83 ns. BaF_2, however, shows a saturation effect from the first to the eighth septuplet caused by pile-up of the slow scintillation component.

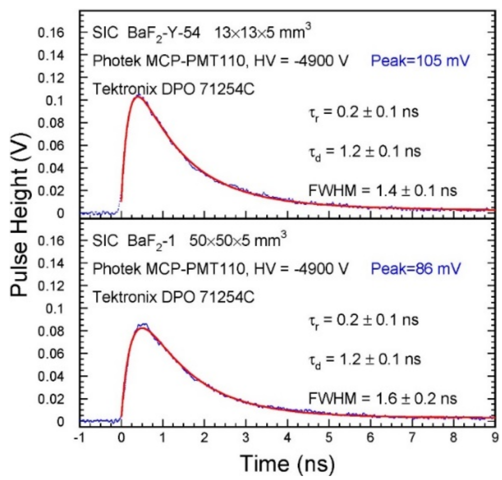

Fig. 3. Singlet bunch measured by BaF_2:Y (top) and BaF_2 (bottom) coupled to the Photek MCP-PMT110.

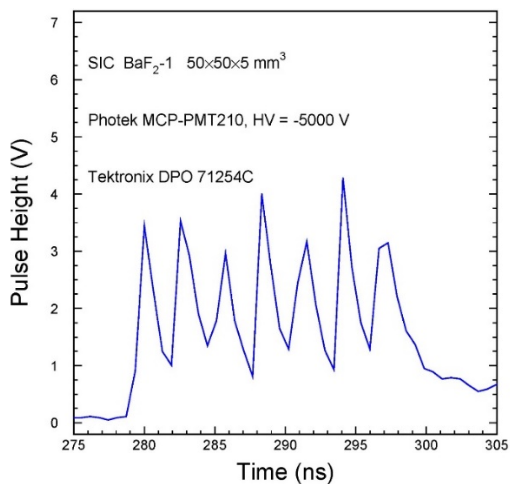

Fig. 4. Septuplet with 2.83 ns bunch spacing observed by BaF_2 coupled to the Photek MCP-PMT 210.

Table I is a summary of the temporal response for all crystals measured by the Photek MCP-PMT 210. Samples are ordered based on their FWHM values to the singlet bunch. Compared to BaF_2, ZnO:Ga, YAP:Yb and YAG:Yb have a slower response, but with FWHM less than 3 ns. Conventional cerium doped fast inorganic scintillators, such as LYSO:Ce, LuAG:Ce and GAGG:Ce, however, are a way too slow to observe a clear septuplet structure with 2.83 ns bunch spacing. Replacing 15 m cable with 1 m cable, BaF_2:Y and BaF_2 show sub-ns FWHM pulse width, which is the shortest among all samples.

It is also interesting to note that cerium doped crystals are featured with a slow rise time, which may limit their timing resolution.

Table I Temporal Response of Fast Crystals Scintillators

Crystal	Emission Peak (nm)	LO (p.e./MeV)	Rise Time (ns)	Decay Time (ns)	FWHM (ns)
BaF_2:Y	220	258	0.2	1.0	1.4
BaF_2	220	209	0.2	1.2	1.5
YAP:Yb	350	9.1*	0.4	1.1	1.7
ZnO:Ga	380	76*	0.4	1.8	2.3
YAG:Yb	350	28.4*	0.3	2.5	2.7
Ga_2O_3	380	259	0.2	5.3	7.8
YAP:Ce	370	1605	0.8	34	27
LYSO:Ce	420	4841	0.7	36	28
LuYAP:Ce	385	1178	1.1	36	29
LuAG:Ce Ceramic	520	1531	0.6	50	40
YSO:Ce	420	3906	2.0	84	67
GAGG:Ce	540	3212	0.9	125	91

* Excited by Alpha particles.

IV. Summary

Temporal response of a dozen fast and ultrafast inorganic scintillators was measured at the APS 10-ID-B test beam site by using 30 keV x-ray bunches with ps bunch length. BaF_2 shows the highest amplitude and fastest response. Septuplet structure with 2.83 ns spacing are clearly observed by both BaF_2:Y and BaF_2 coupled to Photek MCP-PMT, indicating the feasibility of an ultrafast scintillator and photodetector-based front imager concept for the proposed MaRIE project. BaF_2:Y shows no pile-up for multiple septuplets, demonstrating importance of slow component suppression. Other ultrafast inorganic scintillators, such as YAP:Yb, ZnO:Ga and YAG:Yb, show a wider pulse width than BaF_2. Development of ultrafast inorganic scintillators will continue along these lines for future HEP experiments and GHz X-ray imaging.

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