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CHARACTERIZATION OF Ce-DOPED SCINTILLATING CRYSTALS FOR IMAGING ELECTRON BEAMS AT THE APS LINAC

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Abstract

There is growing interest in using inorganic crystals as radiation converters to determine transverse profiles and emittance of electron beams. Some of the more commonly available Ce-doped scintillating crystals are characterized. Electrons generated from a low-emittance rf thermionic gun are accelerated to 220 MeV through the Advanced Photon Source (APS) S-band linear accelerator. Visible fluorescence from the beam interaction with the crystal is transported by a set of achromatic lenses out of the radiation environment for viewing with a charge-coupled device (CCD) or streak camera. LSO:Ce (Lu_2SiO_5) and YAG:Ce ($Y_3Al_5O_{12}$) crystals are directly compared to optical transition radiation (OTR) techniques to determine decay times and conversion efficiency. Streak images of LSO and YAG excited by the e-beam's 8-ns macropulse show FWHM response times of 40 and 89 ns, respectively. Spectral contents for LSO:Ce, YAG:Ce, and YAP:Ce ($YAlO_3$) are found with a spectrometer using 5- to 30-keV hard x-rays impinging on the crystals. System descriptions and test results are discussed.

1 INTRODUCTION

Visible light converters are routinely used as diagnostics to characterize electron beam profiles. Because of the vast difference in the properties of beams generated at the APS and the beam quality goals set for the free-electron laser, demands on the specifications for scintillators has been growing. First-order selection criteria when choosing a scintillation material generally include: surface quality, physical size, fabrication, thermal effects, vacuum compatibility, activation, and radiation damage thresholds. A class of materials that satisfies these basic criteria is inorganic crystals. To further break down the performance specifications we look at conversion efficiency, transition time, spectral emission, and saturation effects. With the recent availability of cerium-doped compounds we chose to study these parameters for the Ce-doped crystals more closely. Measurement techniques and results will be discussed.

2 EXPERMENTAL BACKGROUND

2.1 *Crystals*

We chose three of the cerium-doped crystals to examine: yttrium aluminum garnet (YAG:Ce), lutetium oxyorthosilicate (LSO:Ce), and yttrium aluminum perovskite (YAP:Ce). Both the YAG and YAP were procured as polished discs [1]. The LSO crystal was produced from a rough sample supplied by the manufacturer that was cut to size and polished in house [2]. The crystals appeared to be mechanically stable and exhibited very good resistance to breakage during fabrication and fixturing. Also the crystals showed excellent conformance to high vacuum and great resistance to radiation damage. Some of the pertinent information is given in Table 1.

Table 1: Crystal Description

Crystal Type	Thickness/ Diameter	Ce Dopant Concentration
YAG:CE ($Y_3Al_5O_{12}$)	460 μm/ 2.5 cm	0.05%
LSO:Ce (Lu_2SiO_5)	530 μm/ 1.0 cm	0.2%
YAP:Ce ($YAlO_3$)	460 μm/ 2.5 cm	NA*

** Not Available*

2.2 *Spectrometer*

Spectral emission data for the crystals were taken with an Oriel imaging spectrometer model MS5257 [3]. The grating selected was 300 lines per millimeter, and the output was imaged by a standard ½" format CCD camera [4]. The x-ray beam source was from one of the bending magnet beamlines in the APS 7-GeV storage ring [5]. After passing though a steel filter, the synchrotron radiation has a broad spectrum peaked at 30 keV. The scintillation light was reflected by a mirror behind the crystal and focused by a pair of achromatic lenses onto the entrance slit of the spectrometer. The data were captured with a Data Cube Max Video 200 frame grabber system.

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2.3 *Linac Set Up*

The APS injector's thermionic rf gun produces an electron beam with an 8-ns macropulse that is accelerated through the APS 2856-MHz linac to 220 MeV [6]. The crystals are inserted at the end of the linac using a remote-controlled pneumatic actuator. The plane of the crystal is normal to the e-beam. Since the crystal is translucent, the forward radiation can be imaged from the rear surface of the scintillator. This is desirable since you do not need to account for an angular perspective when using a calibration mask on the crystal for transverse beam profile measurements. A pellicle mirror mounted at 45 degrees behind the crystal reflects the scintillation light out through a quartz vacuum view port into an optical transport to an optics hutch. The transport optics consist of two sets of 6" achromatic lenses and mirrors that are shrouded by anodized tubing. The light is delivered out of the radiation environment to an optics table where the image can be viewed with either a CCD or streak camera [7].

3 RESULTS AND DISCUSSION

Spectral emissions of the crystals indicate that the YAG is the closest to the center of the visible spectrum of the crystals measured, whereas the peak emission of the YAP occurs in the ultraviolet at 369 nm. This is less desirable because conventional visible optics are not optimized as well for this wavelength. A slight shift in the YAG's peak wavelength was observed from reports by others that state 550 nm [8,9]. The results are shown below in Table 2.

Table 2: Summary of Results

Target Type	Spectral Emission Range (FWHM), Peak Wavelength	Response Time (FWHM)	Relative Conversion Efficiency*
YAG	487-587 nm, 526 nm	89 ns	1.0
LSO	380-450 nm, 415 nm	40 ns	0.46
OTR	Broadband [10]	≈10 fs[11]**	0.0013
YAP	350-400 nm, 369 nm	NA***	NA***

*Normalized to the YAG, **Theoretical Limit, ***Not Available.

Streak images of optical transition radiation were used to verify the e-beam's macropulse, which was measured to be 8.0 ns as shown in Figure 1. Use of this beam as the excitation pulse for the scintillators set the limiting resolution of the measurement to the macropulse length. Both of the crystals examined showed response times of greater than this limit of 89 ns and 40 ns for YAG and LSO, respectfully, as shown in Figures 2 and 3.

The relative conversion efficiency was found by imaging transverse beam profiles. The e-beam was focused by a local quadrupole to beam sizes ranging from 0.50 to 2.0 millimeters containing 0.8 nC of charge. An example of the observed spot size with LSO is shown in Figure 4. The normalized data indicate that the YAG is about twice as bright as the LSO crystal. A possible explanation for the lower conversion efficiency of the LSO as observed in our study could be the difference in spectral response of the CCD detector and transmission efficiency of the CCD glass faceplate at UV wavelengths from the visible.

Although the measured spot sizes for LSO and YAG were within 10% of each other, OTR images consistently resulted in profiles 30 to 40% smaller than those measured with the crystals, alluding to the possible saturation effect believed to be present in the crystals for large charge densities [11,12].

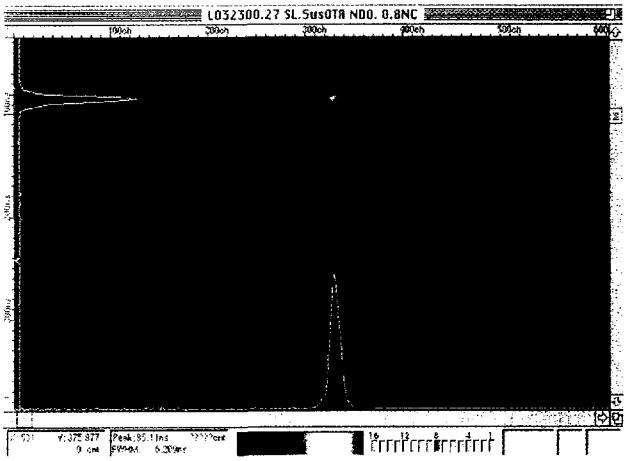

Figure 1: Streak of OTR (Y scale is 400 ns) indicates linac e- beam macropulse length of 8 ns.

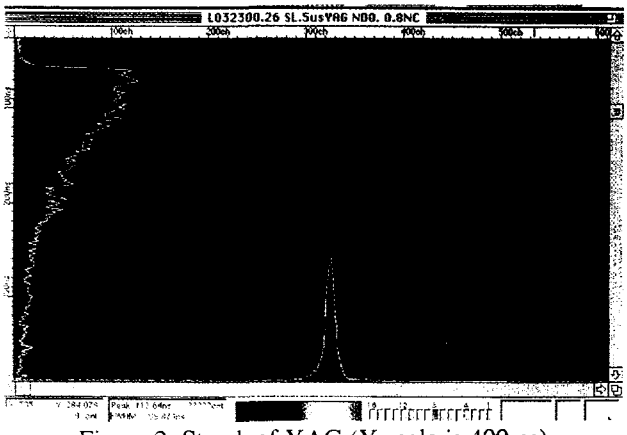

Figure 2: Streak of YAG (Y scale is 400 ns) indicates response time of YAG as 89 ns.

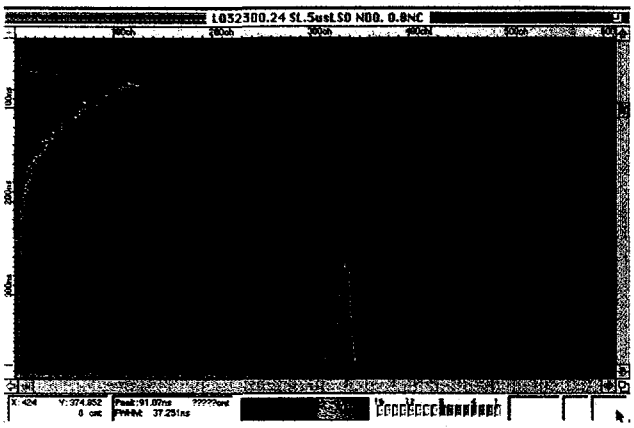

Figure 3: Streak of LSO (Y scale is 400 ns) indicates response time of LSO as 40 ns.

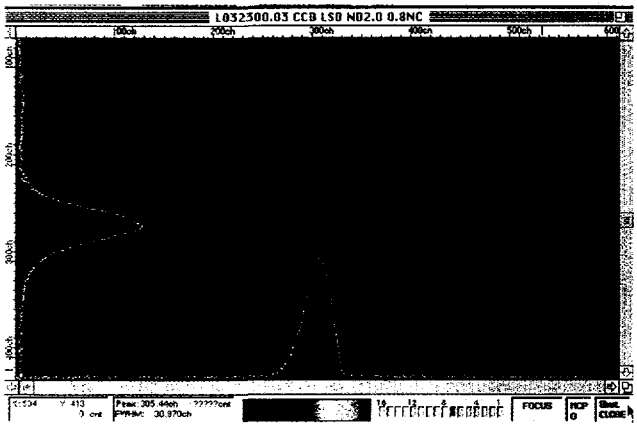

Figure 4: Transverse spot size using LSO crystal. Beam size of approximately 1 mm diameter.

4 CONCLUSIONS

More work is necessary to measure the spatial resolution limits of these scintillators. Factors other than the saturation effect mentioned earlier may limit spatial resolution. Depth of focus, internal reflections, and defects within the crystal can cause image blurring. All of these effects are influenced by the thickness of the crystal. However, limiting the crystal thickness also limits the conversion efficiency or yield. Therefore, a balance between thickness effects and light output should be considered.

The LSO crystal having comparable efficiency to the YAG but with a shorter response time of 40 ns would be preferred if one were interested in resolving temporal information in the regime of 40 to 89 ns. This genre of inorganic crystals has proven to be useful in providing transverse profiles of low charge density beams. These compounds serve well as compliments to OTR methods that are better suited for high intensity accelerator applications.

5 ACKNOWLEDGEMENTS

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