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Evaluation of mass-produced lead tungstate crystals

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Abstract

Because of broad interest in high-energy and nuclear physics community, mass production capacities of lead tungstate (PWO) crystals have been established. The optical and scintillation properties of PWO crystals, 20 each from two major vendors, were evaluated. The transmittance, emission and excitation spectrum, light output, decay kinetics and light response uniformity, as well as their degradation under γ-ray irradiations, were investigated. The radiation-induced color centers and the emission weighted radiation-induced absorption coefficients were measured. It was found that currently mass-produced PWO crystals are radiation hard enough for radiation environment where dose rates of up to a few hundreds rad/h is expected.

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Keywords: Lead tungstate; Crystal; Scintillator; Radiation hardness; Light output

1. Introduction

Lead tungstate crystal ($PbWO_4$ or PWO) is a heavy scintillator with high density ($8.3\,g/cm^3$), short radiation length (0.89 cm) and small Molière radius (2.2 cm). Yttrium-doped $PbWO_4$ crystals have an emission spectrum peaked at 420 nm with FWHM of 120 nm [1]. After extensive R&D, PWO crystals are now in mass production. A few tens of thousands crystals have been produced at Bogoroditsk Techno-Chemical Plant (BTCP) in Tula, Russia, for the CMS experiment at CERN. Shanghai Institute of Ceramics (SIC) in Shanghai, China, has produced a few thousands crystals for the PrimEx experiment at the Jefferson LAB. Two batches of PWO crystals, 20 each randomly selected from mass produced crystals, were evaluated at Caltech. BTCP samples have tapered shape: $30 \times 30\,mm^2$ at the large end, $28.5 \times 28.5\,mm^2$ at the small end and 220 mm long. SIC samples have dimension of $22 \times 22 \times 230\,mm^3$. Fig. 1 shows two typical samples from BTCP and SIC. It is interesting to note that PWO crystals are grown along the *a*-axis

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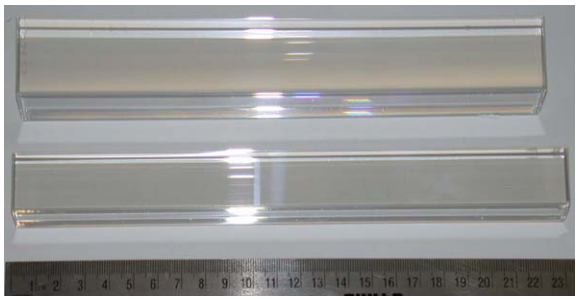

Fig. 1. Typical BTCP (top) and SIC (bottom) PWO samples.

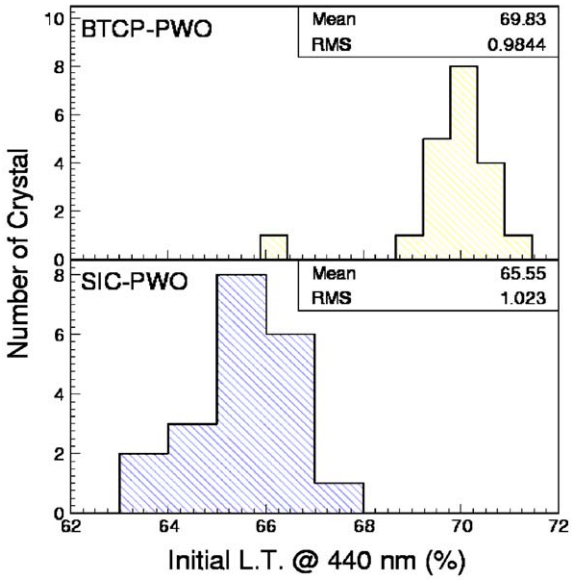

Fig. 2. Initial longitudinal transmittance at 440 nm.

at BTCP by Czochralski method, and are grown along the *c*-axis at SIC by modified Bridgman method [1].

All samples were first annealed at 200 °C for 4 h to remove any residual radiation-induced absorption and to restore the sample to its initial state [2,3]. After annealing, samples were kept in dark at 18 °C for at least 48 h before initial measurement. It was found that PWO optical properties are stable after 8 h of thermal annealing. All samples also went through γ-ray irradiations at 15, 400 and 9000 rad/h until equilibrium [4]. Optical and scintillation properties before and after irradiation were measured.

2. Initial optical and scintillation properties

Longitudinal transmittance was measured by using a Hitachi U-3210 UV/visible spectrophotometer with 0.2% precision [2]. All samples, except one BTCP sample B2465, which has a preexisting color center at 420 nm, show good longitudinal transmittance without visible absorption band. Fig. 2 shows distributions of the initial longitudinal transmittance at 440 nm. The average transmittance at 440 nm is 69.8% with normalized r.m.s. spread of 1.4% for the BTCP samples. The corresponding values for the SIC samples are 65.6% and 1.5%, respectively. Compared to the BTCP samples, the SIC samples has 4.2% lower transmittance. Part of this difference may be explained by the birefringence nature in PWO crystals, since the theoretical transmittance without absorption is about 3% higher if measured along the *a*-axis as compared to the *c*-axis [1,5].

Photo-luminescence was measured with a Hitachi F4500 spectrometer. Within measurement errors, the shape of the emission and excitation spectrum is identical. This result consists with our previous measurement [1]. Light output was measured by using a Hamamatsu R2059 PMT with bialkali cathode at room temperature, and was corrected to 18 °C by using temperature coefficient of −1.98%/°C. PWO crystals from both BTCP and SIC have fast decay time. The ratio of light output between 50 and 100 to 1000 ns is 82.7% and 96.1%, respectively, for BTCP samples. The corresponding numbers are 83.9% and 95.9% for SIC samples. Fig. 3 shows distributions of the light output integrated in 200 ns. The average light output for the BTCP samples is 6.4 p.e./MeV with normalized r.m.s. spread of 12%. The corresponding numbers for the SIC samples are 10.1 p.e./MeV and 9.6%. The light output of the SIC samples is 58% higher than that from the BTCP. This large difference cannot be explained by crystal geometry since the slimmer and longer SIC samples are supposed to have lower light collection efficiency as compared to the