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Growth and characteristic of $Sr_3Tb(BO_3)_3$ crystal

Junye Lu [a,b,*], Feiyun Guo [b], Jianzhong Chen [b]

[a] Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, Fujian 350002, PR China
[b] College of Chemistry and Chemical Engineering, Fuzhou University, Fuzhou, Fujian 350108, PR China

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ABSTRACT

A new borate single crystal of $Sr_3Tb(BO_3)_3$ with dimension $\Phi 20 \times 25\ mm^2$ has been grown by the Czochralski method. The grown crystal was characterized by DTA–TGA, FTIR and X-ray powder diffraction analysis. The results showed the crystal with $[BO_3]^{3-}$ is congruently melting at 1351.35 °C which belongs to hexagonal structure. The hardness of $Sr_3Tb(BO_3)_3$ crystal is 422.5 VDH, and is equal to 5.0 moh. The thermal expansion coefficients were determined to be 2.08×10^{-5}/°C along (1 0 0) direction and 7.43×10^{-6}/°C along (0 0 1) direction and the transmission spectrum was measured in 320–1800 nm at room temperature. The magnetic properties of the single crystal were studied which showed its paramagnetism and magnetic anisotropy. The specific Faraday rotation of single crystal was measured at room temperature in 532, 633, and 1064 nm wavelength. The Verdet constants and magneto-optical figures of merit were investigated. The primary emphasis is laid to explore a new magneto-optical material, all the magneto-optical properties of $Sr_3Tb(BO_3)_3$ are comparing to the ones of TGG.

1. Introduction

Inorganic borates as functional materials have long been a focus of research for their variety of structure type, wide transmittance spectra with high damage threshold, and high optical quality. Studies of alkalimetal and alkaline-earth-metal borates have produced a large family of compounds with outstanding physical properties [1–3]. Furthermore, optical properties of rare-earth ions in crystalline and glassy environments especially Tb^{3+}-doped crystal or glass [4–6] are the subject of intense studies in recent years [7,8]. A new double borate compounds with formula $M_3Ln(BO_3)_3$ (M=Ba, Sr and Ln=La–Lu, Y, Sc) have been reported recently [9–11]. Since the rare earth active ions can substitute for Ln in $M_3Ln(BO_3)_3$ family, it is regarded as laser host materials [12,13].

With the rapid advance in optic communication and optical measurement technology, the research and application of Non-reciprocal magneto-optical devices become more and more important. Terbium gallium garnet (TGG) is thought to be the better material among transparent magnetic materials because of its large Verdet constant [14,15] and good transmittance [16]. However it should be noted that relatively high evaporation of Ga_2O_3 from the melt should be responsible for the deviations from stoichiometry occurring during the TGG crystal growth [17]. Furthermore, magneto-optical glass especially Tb^{3+}-doped glass is known as a type of important optical functional material for its excellent magneto-optical properties and big Verdet constant, but its low relatively stability limits its application [18,19]. Recently, magneto-optical borate crystal has gained interests because of its good transparency in the near ultraviolet [20].

In this work, we firstly report the growth, thermal, spectral, magnetic and magneto-optical properties of $Sr_3Tb(BO_3)_3$ single crystal belonging to $M_3Ln(BO_3)_3$ family which can be used as a new magneto-optical borate material.

2. Experimental

2.1. Material synthesis

The polycrystalline material used for single crystal growth was obtained by the method of solid-state reaction. High purity $SrCO_3$, H_3BO_3 and Tb_4O_7 (5N) were mixed first according to the stoichiometric ratio of $Sr_3Tb(BO_3)_3$, but with 3 wt% excess of H_3BO_3 in order to compensate the loss of H_3BO_3 volatilization in process of solid-state reaction [21]. The chemical reaction formula is as follows:

$$12SrCO_3 + 12H_3BO_3 + Tb_4O_7 \rightarrow 4Sr_3Tb(BO_3)_3 + 12CO_2\uparrow + 18H_2O + 1/2O_2\uparrow$$

Secondly, the well-proportioned admixture was pressed to sheet and sintered for 8 h at 950 °C, and then sintered at 1000 °C for 24 h in air. Finally we obtained white polycrystalline material.

* Corresponding author at: Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, Fujian 350002, PR China.
Tel.: +86 591 83838713.
E-mail address: ljy@fjirsm.ac.cn (J. Lu).

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2.2. Crystal growth

The $Sr_3Tb(BO_3)_3$ crystal was grown by the Czochralski method. An iridium crucible of 55 mm in diameter was utilized to grow the single crystal in N_2 atmosphere with radio frequency (RF) induction heating. The initial growth was started on an iridium wire. The crystal with cracks was pulled up. The powder XRD analysis proved it was single crystal. The seed along (0 0 1) orientation was cut from grown crystal. Consequently, the crystal was grown using this seed and a pulling rate of 0.8 mm/h and a rotating rate of 6–10 rpm. In order to prevent the crystal from cracking, it was cooled to room temperature in 40 h after growth. Finally, $Sr_3Tb(BO_3)_3$ crystal with dimension $\varnothing$ 20 × 25 mm^2 was obtained, as shown in Fig.1, which is transparent and crack free.

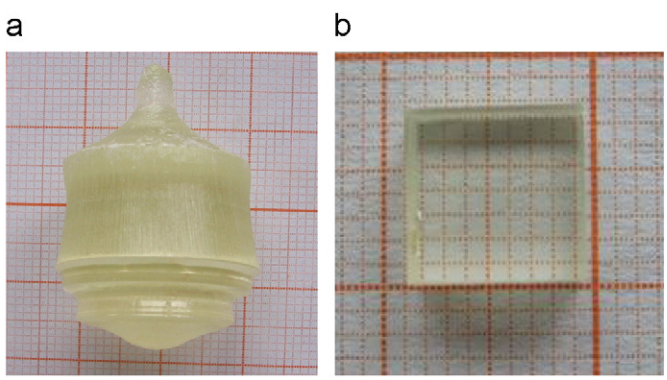

Fig. 1. Grown crystal of $Sr_3Tb\ (BO_3)_3$ (a) and polished sample for spectral measurement (b).

The DTA–TGA measurement was performed up to 1400 °C at a heating rate of 10 °C/min using a SDT Q600 Differential Thermal Analyzer. The results showed that $Sr_3Tb(BO_3)_3$ compound is congruently melting at about 1351.35 °C, as shown in Fig. 2. The hardness of $Sr_3Tb(BO_3)_3$ crystal was determined using a 401MVATM Vickers-microhardometer. The hardness of $Sr_3Tb(BO_3)_3$ crystal is 422.5 VDH, and is about equal to 5.0 moh.

2.3. FTIR spectrum and X-ray powder diffraction

FTIR spectrum was recorded using WQF-300 model Fourier Transform Infrared spectrophotometer with the KBr pellet as the

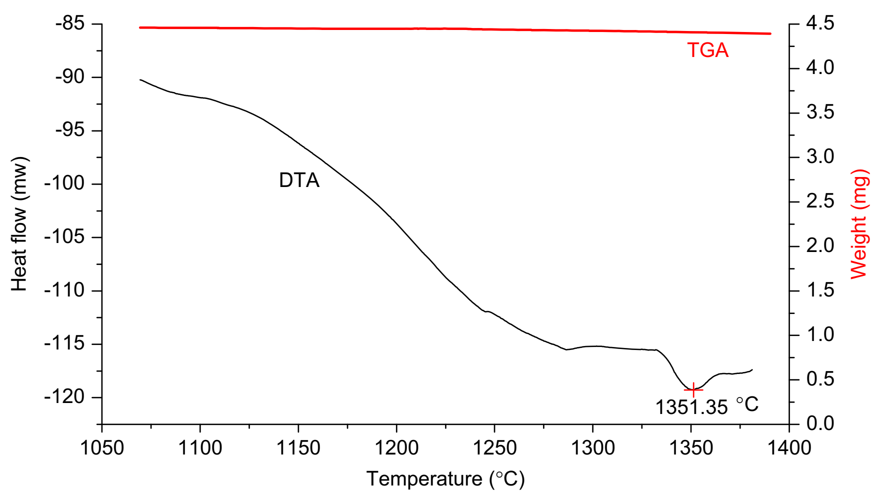

Fig. 2. DTA–TGA curve of $Sr_3Tb(BO_3)_3$ compound.

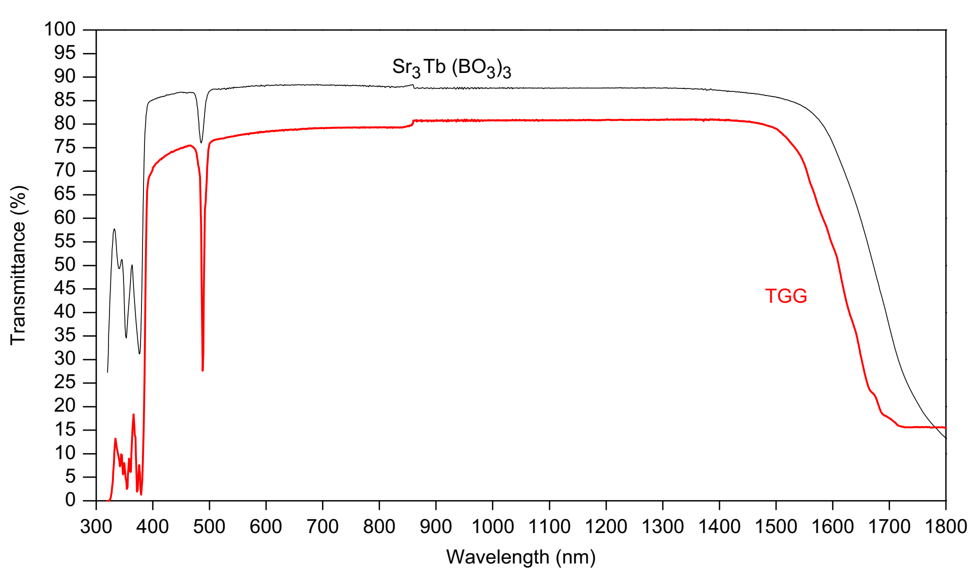

Fig. 3. Transmission spectrum of $Sr_3Tb\ (BO_3)_3$ and TGG crystal.