

## Effect of $\gamma$ -irradiation on spectral properties of undoped $\text{Y}_2\text{SiO}_5$ crystals

Huiyong Pang<sup>1,2</sup>, Guangjun Zhao<sup>\*1</sup>, Liangbi Su<sup>1</sup>, Mingyin Jie<sup>1,2</sup>, Xiaoming He<sup>1</sup>, and Jun Xu<sup>1</sup>

<sup>1</sup> Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Qinghe Road, 390, P. O. Box 800-211, Shanghai 201800, People's Republic of China

<sup>2</sup> Graduate School of the Chinese Academy of Sciences, Beijing 100039, People's Republic of China

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The absorption spectra of undoped  $\text{Y}_2\text{SiO}_5$  crystals were studied before and after  $\gamma$ -irradiation. After  $\gamma$ -irradiation, the additional absorption peaks at 260-270 and 320nm were observed in as-grown and  $\text{H}_2$ -annealed  $\text{Y}_2\text{SiO}_5$  crystal, but it did not occur in air-annealed  $\text{Y}_2\text{SiO}_5$  crystal. These absorption peaks were attributed to F color centers and  $\text{O}^-$  hole centers, respectively. Owing to more oxygen vacancies and color centers in  $\text{H}_2$ -annealed  $\text{Y}_2\text{SiO}_5$  crystal than that in as-grown  $\text{Y}_2\text{SiO}_5$  crystal after  $\gamma$ -irradiation, the additional absorption peaks were more intense in the former than that in the latter. With the irradiation dose increasing from 20 to 220kGy, the intensity of additional absorption peaks increased.

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### 1 Introduction

The yttrium orthosilicate  $\text{Y}_2\text{SiO}_5$  crystal (for simplicity, we will refer to this crystal as YSO) is an optical material. YSO crystal is a monoclinic biaxial system with a  $\text{C}_{2h}^{62}$  ( $\text{C}2/c$ ) space group, which is a structure of low local symmetry. It congruently melts at about 2070°C [1]. And it possesses many excellent properties in various application fields when it is doped with various rare earth ions or transition metal ions. For example,  $\text{YSO}:\text{Ce}^{3+}$  possesses the high light yield and the short decay time as an excellent scintillator [2], and it is widely applied in high-energy ray probing fields [3].  $\text{YSO}:\text{Yb}^{3+}$  and  $\text{YSO}:\text{Pr}^{3+}$  are some of the best candidates as solid laser materials [4-6]. YSO doped  $\text{Eu}^{3+}$  is an excellent optical memory material. Moreover, we can use  $\text{YSO}:\text{Cr}^{4+}$  crystal as a solid-state saturable absorber [7], which has been applied with alexandrite ( $\text{BeAlO}_4:\text{Cr}^{3+}$ ) and  $\text{LiCAF}_2:\text{Cr}^{3+}$  laser as a tunable passive Q-switched element. Undoped YSO crystal can be used as epitaxial substrate. In briefly, YSO crystal is a good multifunctional material.

Shoudu Zhang et al. had grown the undoped YSO single crystal by the Czochralski technique [8], but they didn't further study the spectral properties of the crystals. The color centers that are deleterious to spectral properties would be produced after irradiation, so it is very important that crystals possess outstanding irradiation properties as optical materials. But study of effect of  $\gamma$ -rays irradiation on spectral properties of YSO crystals is less known.

In this paper, The effect of  $\gamma$ -irradiation on spectral properties of undoped YSO crystal was analyzed and discussed.

### 2 Experimental

YSO crystal was grown by the RF-heating Czochralski method. High-purity nitrogen gas was used as protective atmosphere. All samples were cut from the as-grown crystal. After optically polished, the (010) face

\* Corresponding author: e-mail: zhaoguangjun@163.net, huiyongpang@yahoo.com.cn

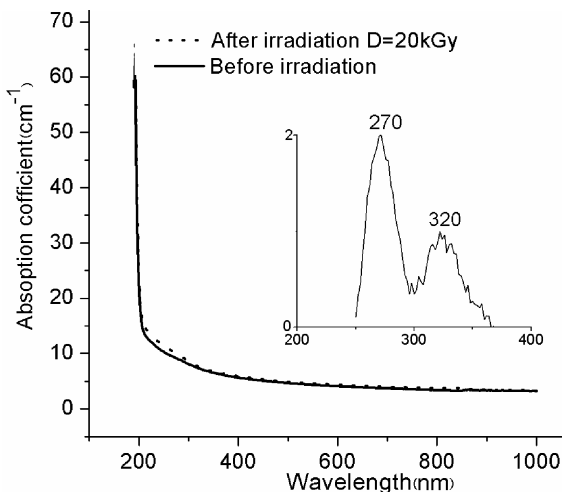
samples with thickness of 0.6mm were annealed in hydrogen gas or air at 1200°C for 24h. The samples were irradiated by  $\gamma$ -rays from a  $^{60}\text{Co}$  source with a dose rate of 10kGy/h for the total irradiation dose of 20 and 220kGy at room temperature.

Optical absorption spectra were recorded by the V-570 type ultraviolet/visible/near-IR spectrophotometer (Japan JASCO Inc). All measurements were performed at room temperature.

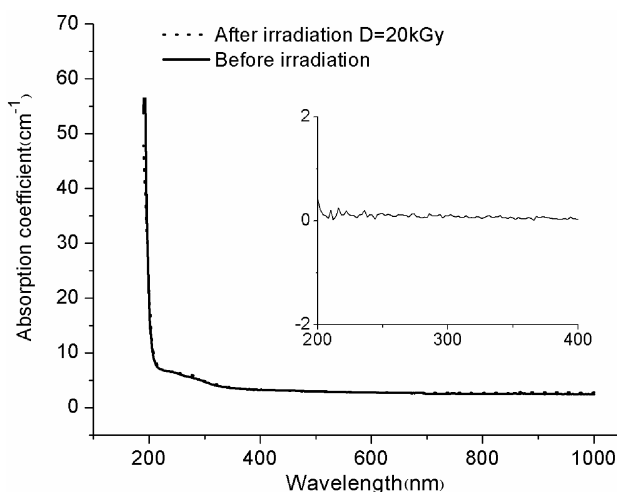
### 3 Results and discussion

The as-grown and annealed YSO samples were irradiated by  $\gamma$ -rays at room temperature. Air-annealed sample and as-grown sample kept colorless after irradiation, and the  $\text{H}_2$ -annealed sample became gray in a way after irradiation. The additional absorption (AA) spectrum was calculated to study the effect of  $\gamma$ -irradiation. The AA values were determined as  $(\alpha_2 - \alpha_1)$ , where  $\alpha_2$  and  $\alpha_1$  were absorption coefficients of the samples after and before  $\gamma$ -irradiation, respectively. The absorption spectra after and before  $\gamma$ -irradiation with doses of 20 and 220kGy and AA spectra of as-grown, air-annealed and  $\text{H}_2$ -annealed YSO samples are shown in figs. 1, 2 and 3.

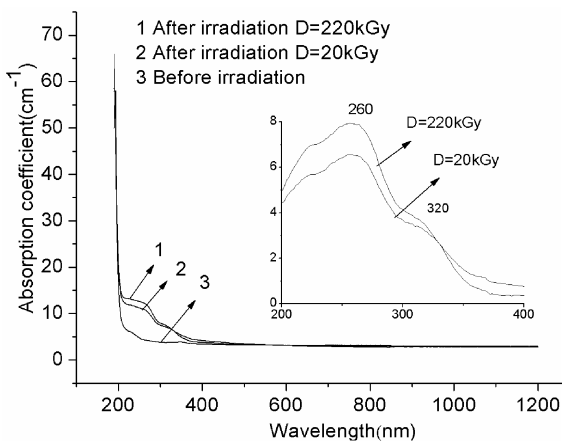
The additional absorption peaks at 260-270 and 320nm are observed in as-grown YSO crystal and  $\text{H}_2$ -annealed YSO crystal after irradiation as shown in figures 1 and 3. Moreover, the additional absorption peaks become more intense with the irradiation dose increasing from 20 to 220kGy as shown in figure 3. But there is not obviously additional absorption peak in air-annealed YSO crystal after irradiation as shown in figure 2.



**Fig. 1** The absorption spectra of as-grown YSO crystal before and after irradiation, and the additional absorption spectrum is shown in inset.



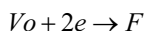
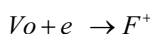
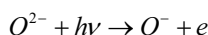
**Fig. 2** The absorption spectra of air-annealed YSO crystal before and after irradiation, and the additional absorption spectrum is shown in inset.



**Fig. 3** The absorption spectra of  $\text{H}_2$ -annealed YSO crystal before and after irradiation, and the additional absorption spectra are shown in inset.

S. Baccaro et al. researched the effect of irradiation on color centers in YAP, and they reported that the induced absorption band in the vicinity 260-270 nm was caused by F (Vo +2e) centers [10]. And A. Matkovski et al. [11] proposed that the absorption band near 32000cm<sup>-1</sup> was caused by hole centers O<sup>-</sup> in irradiated YAG. They drew a conclusion that the formation of color centers depended on the growth conditions of the crystals, such as growth method and growth atmosphere, etc [11]. YSO crystal in this experiment was grown by the same method and atmosphere as those in references [10,11]. So the additional absorption band near 260-270nm should be caused by same F-type color centers and the absorption band near 320nm should be attributed to O<sup>-</sup> centers in irradiated crystal in this experiment.

Owing to existing some oxygen vacancies in CZ grown crystal. When the  $\gamma$ -photons pass through the matter they will interact with the atoms of matter to produce secondary electrons. The Compton effect is the main mechanism when energy of photons is larger than 0.1 MeV. An photon of  $\gamma$ -rays collides with an electron in the valence band, and ejects the electron from the atom. A photon of lower energy (Compton electron) than the original is produced, which travels at an angle from the direction of the incident photon [9]. Oxygen vacancies in the crystal lattice would trap one or two electrons and form F-type color centers (F centers and F<sup>+</sup> centers). This reaction may simply be expressed as



The quantity of the ionized electrons increased with the radiation dose. So the concentrations of O<sup>-</sup> hole centers and F-type color centers also increased with the radiation dose. And the additional absorption peaks corresponding became more intense as shown in figure 3.

Why are the additional absorption peaks in H<sub>2</sub>-annealed crystal more intense than that in as-grown crystal after irradiation? And why aren't the additional absorption peaks observed in air-annealed crystal after irradiation? We think these might be involved with concentration of oxygen vacancies.

During the air annealing process, oxygen atoms can diffuse into the lattice to some extent and decrease the concentration of oxygen vacancies, so the concentration of F-type color centers is very low in the air-annealed sample after irradiation. As a result, the absorption spectra of air-annealed crystal don't obviously change before and after irradiation as shown in figure 2.

During the H<sub>2</sub> annealing process, more oxygen atoms can get away crystal, and the concentration of oxygen vacancies increases. So more color centers were produced in H<sub>2</sub>-annealed sample after irradiation.

Therefore, the additional absorption peaks of F-type color centers and O<sup>-</sup> hole centers are more intense in H<sub>2</sub>-annealed crystal than those in as-grown crystal after irradiation as shown in figure 3.

## 4 Conclusions

The absorption spectra of undoped Y<sub>2</sub>SiO<sub>5</sub> crystals before and after irradiation were detailedly studied. Owing to ionization action of  $\gamma$ irradiation, the F-type color centers and O<sup>-</sup> hole centers that can respectively cause the absorption peaks at 260-270nm and 320nm, are produced in as-grown and H<sub>2</sub>-annealed YSO crystals after  $\gamma$  irradiation. And these color centers don't occur in irradiated air-annealed YSO crystal because air-annealing can decrease the concentration of oxygen vacancies in crystal.

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