Study on Photoluminescence and Thermoluminescence of Y2-xSmxMgTiO6 Phosphors

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Abstract

In recent years, double perovskite matrix materials have gained significant attention due to their flexible structure, ease of doping and excellent thermal stability. While studies related to photoluminescence in rare-earth-doped double perovskite matrix materials are common, research specifically focused on thermoluminescence remains relatively scarce. In this study, a series of Y2-xSmxMgTiO6 (0≤x$ $0.1) samples were synthesized using high-temperature solid-state methods. XRD analysis revealed that the crystal structure of the samples belongs to the monoclinic system (space group P21/n), with Sm3+ ions substituting for Y3+ ions in Y2MgTiO6. The PL results indicated that the optimal doping concentration was Y1.95Sm0.05MgTiO6, which exhibited emission peaks at 568 nm, 605 nm, 652 nm, and 715 nm under blue light excitation at 409 nm. TL measurements for different doping concentrations showed that Y1.98Sm0.02MgTiO6 phosphors exhibited the strongest TL signal. The TL peaks observed at 530 K and 610 K corresponded to defects in the matrix and Sm3+ dopants, respectively. The Tm-Tstop analysis revealed that the TL curve of Y1.98Sm0.02MgTiO6 phosphors was a superposition of seven peaks. Computerized glow curve deconvolution (CGCD) was performed on the TL of the sample according to the results of three-dimensional thermoluminescence spectra (3D-TL) and Tm-Tstop; the trap depths in the sample were estimated to range from 0.69 eV to 1.49 eV. Additionally, the lifetimes of each overlapping peak were calculated using fitting parameters. Furthermore, the dose response test showed that the saturation dose of the sample was higher, which was 9956 Gy. Therefore, this material can serve as a thermoluminescence dosimeter for high-dose measurements. The saturation dose for the lowest-temperature overlapping peak was found to be 102 Gy, which correlates with its specific energy level lifetime, while other overlapping peaks also exhibited favorable linear relationships.

Full Text

Study on Photoluminescence and Thermoluminescence of Y_2 Sm $MgTiO_6$ Phosphors

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Abstract: In recent years, double perovskite matrix materials have gained significant attention due to their flexible structure, ease of doping, and excellent thermal stability. While studies on photoluminescence in rare-earth-doped double perovskites are common, research specifically focused on thermoluminescence remains relatively scarce. In this study, a series of Y_2 Sm $MgTiO_6$ ($0 \leq x \leq 0.1$) samples were synthesized using high-temperature solid-state methods. XRD analysis revealed that the crystal structure belongs to the monoclinic system (space group $P2_1/n$), with Sm^{3+} ions successfully substituting for Y^{3+} in Y_2MgTiO_6. Photoluminescence results indicated that the optimal doping concentration was $Y_{1\cdot95}Sm_{0\cdot05}MgTiO_6$, which exhibited emission peaks at 568 nm, 605 nm, 652 nm, and 715 nm under blue light excitation at 409 nm. Thermoluminescence measurements for different doping concentrations showed that $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ phosphors exhibited the strongest TL signal. The TL peaks observed at 530 K and 610 K corresponded to defects in the matrix and Sm dopants, respectively.

The T -T analysis revealed that the TL curve of $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ phosphors was a superposition of seven peaks. Computerized glow curve deconvolution (CGCD) was performed on the TL spectrum based on results from three-dimensional thermoluminescence spectra (3D-TL) and T -T analysis. The trap depths in the sample were estimated to range from 0.69 eV to 1.49 eV. Additionally, the lifetimes of each overlapping peak were calculated using fitting parameters. Furthermore, dose response tests showed that the saturation dose of the sample was 9956 Gy. Therefore, this material can serve as a thermoluminescence dosimeter for high-dose measurements. The saturation dose for the lowest-temperature overlapping peak was found to be 102 Gy, which correlates with its specific energy level lifetime, while other overlapping peaks also exhibited favorable linear relationships.

Keywords: Y_2MgTiO_6; Thermoluminescence; T -T ; Computerized Glow Curve Deconvolution; Dose Response

INTRODUCTION

Studies have shown that the optical and dosimetric properties of oxide matrix materials doped with rare earth ions can be improved [1–5]. Among oxide matrix materials, double perovskites have attracted much attention due to their excellent chemical structure and good stability [6]. AA BB O_6-type double perovskites can be obtained by partially substituting A or B sites of ABO_3-type simple perovskites with different A or B ions. As a new type of matrix material, the structure and luminescence properties of double perovskites have been extensively studied. For example, La_2MgTiO_6 [7], Gd_2ZnTiO_6 [8], and La_2MTiO_6 (M=Co,Ni) [9] exhibit good thermal stability and superior luminescence properties, making them candidate materials for lighting applications. However, their thermoluminescence properties have rarely been studied. The Y_2MgTiO_6 matrix material has become a research hotspot in recent years due to its physicochemical stability, easy preparation, and wide availability of raw materials [10].

Thermoluminescent materials contain luminescent centers and traps. Under high-energy radiation excitation, free electrons and holes are generated in the crystal, and some of them are captured by traps. When the crystal is heated, the captured electrons (or holes) are thermally excited to become quasi-free carriers, and thermoluminescence is produced when these carriers recombine with luminescent centers [11,12]. Analysis of the thermoluminescence glow curve can reveal the types and activation energies of traps [13-16]. Most current research uses the Computerized Glow Curve Deconvolution (CGCD) method for analysis. However, if the internal information of the system is unknown, this method lacks physical meaning. If the luminescence characteristics of the thermoluminescent material can be further understood, more accurate and reliable results can be obtained.

Many thermoluminescent materials exhibit good linearity in dose response, easy fabrication, and low cost [17-19], making them suitable for ionizing radiation dose detection. For example, LiF:Mg,Cu,P [20] and $Li_2B_4O_7$:Mn [21] can be used for personal dose detection; BeO [22], $CaSO_4$:Dy [23], and CaF_2:Dy [24] for environmental dose detection; and Al_2O_3:C [25], MgB_4O_7:Dy [26] for medical dose detection. In addition to standard thermoluminescence dosimeters, other materials may be used for dose detection, such as $SrGd_2O_4$:Sm, (Sr,Ba)AlO_4:Eu, $LaGa_4O(BO_3)_3$, and (Ba,Sr)TiO_3:Pr [27-32]. The sensitivity of general thermoluminescence dosimeters is high, but the linear upper limit of dose response is typically not very high (about 200 Gy). In some special applications (such as irradiation preservation), it is often necessary to accurately measure irradiation doses at the kGy level [33,34]. Therefore, studying thermoluminescent materials with stable performance and a wide range of dose response linearity can expand the application field of thermoluminescence technology.

II. EXPERIMENT

A. Sample Preparation

Y_2 Sm $MgTiO_6$ (x = 0, 0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, and 0.2) series phosphors were synthesized by high-temperature solid-state method. Stoichiometric amounts of Y_2O_3 (99.99%), MgO (99.99%), TiO_2 (99.99%), and Sm_2O_3 (99.99%) were weighed and placed in an agate mortar. The mixture was ground thoroughly for 0.5 h until uniformly mixed. The ground powder was placed in a corundum crucible and pre-sintered in a muffle furnace at 800 °C for 3 h in air atmosphere to prepare for the solid-phase reaction. The temperature was then increased to 1300 °C at a faster heating rate (7 °C/s) and calcined at 1300 °C for 9 h. The block-shaped sintered samples were obtained, then crushed and ground with an agate mortar to obtain phosphor powder.

B. Testing Methods

The XRD patterns of different samples were measured using a Rigaku Ultima IV X-ray diffractometer with Cu-Kα radiation, a scanning range of 10°–80°, and a scanning rate of 5°/min. The photoluminescence spectra were measured using a HITACHI F-7000 fluorescence spectrometer with a Xe lamp excitation source and spectral resolution of 0.2 nm. Thermoluminescence measurements were performed using a Risø TL/OSL-15-B/C thermoluminescence/optically stimulated luminescence measurement instrument. The irradiation source was a Sr-90 β radiation source equipped with the instrument, with a dose rate of about 0.1 Gy/s, radioactivity of 1.4 GBq, distance between the radiation source and sample of 5 mm, distance between the detector and sample of 55 mm, and heating rate of 5 K/s during measurement. Three-dimensional thermoluminescence spectroscopy was measured using an LTTL3DS thermoluminescence spectrometer (Guangzhou Ruidi Technology Co., Ltd.). The irradiation source was an X-ray tube operating at 50 kV and 150 µA, with a dose rate of about 0.1 Gy/s, heating rate of 5 K/s during measurement, heating range of 300–750 K, spectral range of 300–1000 nm, and spectral resolution of 1 nm.

[Figure 1: see original paper] XRD Spectra of Y_2 Sm $MgTiO_6$ (x=0, 0.005, 0.01, 0.02, 0.05 and 0.1) Samples

III. RESULTS AND DISCUSSION

A. XRD Analysis

The XRD patterns of Y_2 Sm $MgTiO_6$ (x = 0, 0.005, 0.01, 0.02, 0.05, and 0.1) series samples are shown in Fig. 1. There is no information for Y_2MgTiO_6 in the inorganic crystal structure database. Shannon [35] used the Rietveld method to analyze the data, proving that Dy_2MgTiO_6 and Y_2MgTiO_6 have very similar structures. Therefore, the standard card of Dy_2MgTiO_6 (ICDD 04-021-1637) was used as a reference. As can be seen from the figure, the number and position of the X-ray diffraction peaks of different samples are basically consistent with the standard card, and the diffraction angle (33°) belonging to the characteristic site shifts to a smaller angle [36,37]. According to the Bragg equation [38,39], a shift to smaller diffraction angles indicates increased lattice spacing. The ionic radii of each element in the lattice system are r(Y^{3+}) = 0.1019 nm, r(Mg^{2+}) = 0.0720 nm, r(Ti^{4+}) = 0.0605 nm [40], and the ionic radius of Sm^{3+} is 0.1132 nm. The shift of the diffraction angle to smaller values proves that Sm^{3+} with a larger ionic radius successfully entered the lattice to replace Y^{3+} with a smaller ionic radius, without changing the lattice structure and charge configuration. The sample remains monoclinic $P2_1/n$ [37].

[Figure 2: see original paper] shows the morphology and lattice fringes of the Y_2MgTiO_6 matrix and Sm-doped Y_2MgTiO_6. The phosphor morphology is irregular, with larger particles of 2 μm and smaller particles of 400 nm. The lattice fringes become more dense after Sm doping, indicating decreased crystal plane spacing, which proves that Sm^{3+} with larger ionic radius successfully entered the matrix lattice. Combined with XRD results, this confirms that the phosphor was successfully prepared under these experimental conditions.

B. Photoluminescence Analysis

[Figure 3: see original paper] shows the photoluminescence spectra of Y_2 Sm $MgTiO_6$ (x = 0.001, 0.002, 0.005, 0.01, 0.02, 0.05, and 0.1) series phosphors. When the monitoring wavelength is 605 nm, the excitation spectrum extends from 340 nm to 500 nm. The strongest absorption peak is at 409 nm, belonging to the characteristic transition of Sm^{3+}: $^6H_5/_2 \rightarrow {}^4F_7/_2$. The absorption peaks at 349 nm, 366 nm, 379 nm, 422 nm, 443 nm, and 474 nm correspond to the characteristic transitions of Sm^{3+}: $^6H_5/_2 \rightarrow$ $^6P_5/_2$, $^4P_3/_2$, $^4D_3/_2$, $^4I_{13}/_2$, respectively [41]. When excited by 409 nm violet light, four obvious emission peaks appear at 568 nm, 605 nm, 652 nm, and 715 nm, corresponding to the characteristic transitions of Sm^{3+}: $^4G_5/_2 \rightarrow$ $^6H_5/_2$, $^6H_7/_2$, $^6H_9/_2$, $^6H_{11}/_2$, respectively [42,43]. With increasing Sm doping concentration, the position and shape of the emission peaks do not change, while the emission intensity first increases and then decreases. When the Sm doping concentration is x = 0.05, the photoluminescence emission intensity is maximum, and obvious concentration quenching occurs with further increase in doping concentration.

C. Doping Concentration Optimization

To determine the phosphor with the best TL yield, the thermoluminescence peak was optimized by varying the Sm doping concentration. Samples with different doping concentrations (30 mg each) were prepared for TL testing. The test procedure was: (1) preheat the sample to 773 K and hold for 10 s; (2) cool to room temperature; (3) irradiate with a Sr-90 β radiation source for 100 Gy; (4) measure TL (heating rate 5 K/s). The results are shown in [Figure 4: see original paper]. With increasing Sm doping concentration, the thermoluminescence integral intensity gradually increases and reaches its maximum when x = 0.02. This sample was selected for subsequent analysis. With further introduction of Sm, concentration quenching occurs and the thermoluminescence integral intensity decreases. The Y_2MgTiO_6 matrix itself shows a weak thermoluminescence peak between 460 K and 630 K. After introducing Sm, the thermoluminescence peak of the phosphor is obviously extended to higher temperatures, with significant thermoluminescence also observed at 675 K. Additionally, the shape of the thermoluminescence curve changes with Sm doping concentration. As shown in the inset of [Figure 3: see original paper], when x < 0.02, the thermoluminescence peak around 610 K is stronger, significantly larger than the peak intensity around 530 K. When x > 0.02, the peak around 530 K becomes larger than that around 610 K. When x $= 0.02$, a balanced state is achieved. When concentration quenching occurs, the decrease rate of the peak intensity around 610 K is obviously faster than that of the peak at 530 K.

To explain these phenomena and further understand the internal thermoluminescence mechanism of Y_2 Sm $MgTiO_6$ phosphors, three-dimensional thermoluminescence spectra of four standard samples irradiated by X-rays for 100 Gy were measured, as shown in [Figure 5: see original paper]. [Figure 5a: see original paper] shows that the thermoluminescence range of the Y_2MgTiO_6 matrix is between 480 K and 640 K, with peak temperatures at 530 K and 600 K, which is basically consistent with the curve in [Figure 4: see original paper]. The characteristic emission band of Y_2MgTiO_6 matrix thermoluminescence is around 698 nm. [Figure 5b: see original paper] shows the three-dimensional thermoluminescence spectrum when 0.01 Sm is introduced. The thermoluminescence intensity caused by Sm introduction enhances the thermoluminescence intensity of the Y_2MgTiO_6 matrix, without changing the peak temperature and emission band position of the matrix thermoluminescence. A new thermoluminescence peak appears around 610 K, with emission bands around 570 nm, 600 nm, and 650 nm, which is basically consistent with the characteristic emission shown by Sm^{3+} in PL. From this, it can be inferred that this thermoluminescence peak is caused by Sm^{3+}. The peak intensity around 610 K is obviously larger than that of the matrix at 530 K, which is also consistent with the curve in [Figure 4: see original paper].

The three-dimensional thermoluminescence spectrum for Sm doping concentration x $= 0.02$ is shown in [Figure 5c: see original paper]. With continuous increase of Sm doping concentration, not only the thermoluminescence intensity of Sm^{3+} is enhanced, but also the thermoluminescence intensity of the matrix increases. At this point, the thermoluminescence peak intensity caused by Sm^{3+} (610 K) is basically consistent with that caused by the matrix (530 K), reaching a balanced state in the thermoluminescence spectrum. With further increase in doping concentration, the thermoluminescence intensity caused by Sm^{3+} decreases significantly, and the thermoluminescence peak caused by the matrix also decreases, but the decrease is much smaller than that of Sm^{3+}. This indicates that the thermoluminescence emission of Sm^{3+} is greatly affected by concentration quenching, while the concentration quenching effect has little impact on the matrix. This explains why the thermoluminescence peak intensity at 530 K is larger than that at 610 K after excessive introduction of Sm^{3+}.

To determine the energy dependence under X-ray and β-particle irradiation, the thermoluminescence spectra of four samples under X-ray irradiation were measured by the Risø instrument and compared with those under β-particle irradiation. The results are shown in [Figure 6: see original paper]. The thermoluminescence spectra under X-ray and β-particle irradiation are basically the same, with only slight differences in the low-temperature region.

D. T -T Method

To confirm the number of overlapping peaks and their peak temperatures in the thermoluminescence spectrum of the $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ sample, enabling fitting using the CGCD method and further exploring the thermoluminescence mechanism and kinetic parameters, peak separation experiments were performed using the T -T method. The test procedure was: (1) irradiate the sample with a Sr-90 β radiation source at a dose of 100 Gy; (2) heat the sample to a sufficiently high temperature (T) to clear the TL signal before the T temperature value; (3) reheat the sample at the same heating rate (5 K/s), recording the remaining TL curve and noting the position of the first maximum T on the TL curve. Subsequently, the entire process was repeated with a slightly lower T value (approximately 3 K lower).

[Figure 7: see original paper] illustrates the relationship between T and T , showing seven plateaus, each representing a thermoluminescence peak. The peak temperatures T for each overlapping peak are: 384, 419, 449, 532, 581, 610, and 640 K. Within the temperature range below 449 K, the peak temperatures of the three overlapping peaks vary with T , indicating significant trap recapture electron processes, which aligns with second-order kinetic behavior. After 532 K, the peak temperatures of the remaining four overlapping peaks remain relatively constant with T , suggesting that trap recapture electron processes can be neglected, consistent with general or first-order kinetic behavior.

E. Computerized Glow Curve Deconvolution (CGCD)

The CGCD method is widely used to study complex TL mechanisms. The position, shape, and dynamic parameters of overlapping peaks in TL curves can be obtained using CGCD [44]. Combined with results from three-dimensional thermoluminescence spectroscopy and the T -T method, CGCD was used to fit the TL curve of $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ sample irradiated by Sr-90 β radiation source for 100 Gy. Each overlapping peak can be expressed by Formula 1 [45]:

$$I(t) = sn_0 \exp\left(-\frac{E}{kT}\right) \cdot \left[1 + \frac{s(b-1)}{\beta}\int_{T_0}^{T} \exp\left(-\frac{E}{kT'}\right) dT'\right]^{-\frac{b}{b-1}}$$

In Formula 1: n_0 is the initial number of captured electrons in the trap level; E is the activation energy of captured electrons (in eV); s is the frequency factor (in Hz); k is the Boltzmann constant (0.862×10^{-4} eV/K); β is the heating rate of the sample (5 K/s in this experiment); T is absolute temperature (in K); b is the kinetic order.

The CGCD fitting result is shown in [Figure 8: see original paper]. The fitting curve is in good agreement with experimental points, and the fitted parameters are shown in . The kinetic parameters obtained through CGCD fitting allow calculation of the energy level lifetime for each overlapping peak, which is crucial for estimating the saturation dose of each peak. The energy level lifetime for different overlapping peaks can be determined using Formula 2 [46]:

$$\tau = s^{-1} \cdot e^{\frac{E}{kT}}$$

In Formula 2: τ represents the energy level lifetime of the overlapping peak; s is the frequency factor; E denotes the trap depth; k is the Boltzmann constant; T is ambient temperature (typically 300 K). The calculated results are summarized in . Notably, the energy level lifetime of the low-temperature overlapping peak at 378 K is relatively short, measuring only 980 seconds. In contrast, the energy level lifetime increases for deeper traps, as electrons captured by low-temperature peak traps are more readily released.

In [Figure 8: see original paper], the peak temperatures of the seven overlapping peaks after CGCD fitting are: 378 K, 415 K, 477 K, 534 K, 578 K, 615 K, and 654 K. Correspondingly, the trap depths extend from 0.69 eV to 1.49 eV. The b-values for the three overlapping peaks at 378 K, 415 K, and 477 K are 2.0, while the overlapping peak at 534 K has a b-value of 1.6. The three overlapping peaks at 578 K, 615 K, and 654 K have b-values of 1.2, 1.2, and 1.0, respectively, which closely align with the T -T method results. Furthermore, the fitted peak temperatures for overlapping peaks at 477 K, 534 K, 578 K, 615 K, and 654 K closely match the image in [Figure 5c: see original paper]. Specifically, the three overlapping peaks at 477 K, 534 K, and 578 K are attributed to the Y_2MgTiO_6 matrix, while those at 615 K and 654 K are associated with Sm^{3+}. However, the overlapping peaks at 378 K and 415 K were not observed in [Figure 5c: see original paper], possibly due to experimental errors arising from different excitation sources. These results demonstrate that by exploring the internal mechanism of the system, the overlapping peak positions and kinetic parameters obtained by CGCD fitting have scientific basis and reliability.

F. Dose Response

The TL dose response test of $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ phosphor was carried out as follows: (1) preheat the sample to 773 K and hold for 10 s; (2) cool to room temperature; (3) irradiate with Sr-90 β radiation source; (4) measure TL (heating rate 5 K/s). This procedure was repeated for doses of 2, 5, 10, 20, 50, 60, 70, 80, 90, 100, 110, 120, 150, 200, 300, 400, 500, 700, 800, 900, 1000, 2000, 5000, 10000, 20000, and 25000 Gy. The results are shown in [Figure 9: see original paper]. With increasing irradiation dose, the shape of the TL curve changes significantly. When the irradiation dose is less than 90 Gy, the peak around 530 K is stronger; when the dose exceeds 90 Gy, the peak around 610 K becomes stronger, indicating that the characteristic thermoluminescence of Sm^{3+} in the $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ system is far more sensitive to irradiation dose than that of the Y_2MgTiO_6 matrix.

[Figure 10: see original paper] shows the change in integral TL intensity with dose. Each experimental point represents the integral area under the TL curve. The dose response may have reached saturation, which can be fitted according to Formula 3 [47]:

$$I(D) = A \cdot \left[1 - \exp\left(-\frac{D}{D_0}\right)\right]$$

In Formula 3: I represents the thermoluminescence integral intensity; A denotes the number of thermoluminescent sensitive units; D stands for radiation dose; D_0 corresponds to the saturation dose. After fitting, the saturation dose of the sample was found to be 9956 Gy. Compared with commonly used thermoluminescence dosimeters (such as LiF:Mg,Cu,P, BeO, Al_2O_3:C), this material has a higher saturation dose, and the dose response maintains good linearity up to 1 kGy.

Because electrons trapped by low-temperature peaks are more easily released, the decay time of trapped electrons at 378 K is only 0.01 days, and at 415 K is 0.3 days. However, the decay time of trapped electrons at 477 K and above exceeds 23 days, indicating longer-term stability. Therefore, this material can be used as a thermoluminescence dosimeter for high-dose applications, such as in fruit radiation preservation.

For a TL curve composed of multiple overlapping peaks, it is possible to fit the dose response using the total integral of TL curves obtained at different irradiation doses. However, due to significant differences in energy level lifetimes of each overlapping peak, some theoretical deviations exist. Nevertheless, within specific dose ranges, these deviations are not pronounced. To explore the dose response characteristics of each overlapping peak in the $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ phosphor system, the CGCD method was employed to fit TL curves at various irradiation doses. The results are depicted in [Figure 11: see original paper]. The peak temperatures T of Peaks 1, 2, and 3 shift toward lower temperatures as irradiation dose increases, consistent with second-order kinetic behavior. Peaks 4, 5, 6, and 7 exhibit no significant change in T with increasing dose, aligning with first-order kinetic behavior and consistent with T -T method results.

With increasing irradiation dose, the thermoluminescence intensity of Peak 1 did not increase significantly after 200 Gy. To explore the dose response curves of different overlapping peaks, the thermoluminescence integral intensity of each overlapping peak under different irradiation doses was analyzed. The results are shown in [Figure 12: see original paper]. Except for Peak 1, the other overlapping peaks show good linear relationships. The slopes of Peaks 6 and 7 are similar, and the slopes of Peaks 3, 4, and 5 are consistent, indicating that Peaks 6 and 7 may be caused by Sm^{3+}, while Peaks 3, 4, and 5 originate from the matrix. The slope of Peak 6 is significantly larger than that of Peak 4, indicating that the characteristic thermoluminescence of Sm^{3+} is much more sensitive to irradiation dose than the matrix.

The dose response of Peak 1 may have reached saturation. After fitting using Formula 3, the saturation dose for Peak 1 is determined to be 102.5 ± 3.2 Gy. Considering that the dose rate of the Sr-90 radioactive source is 0.1 Gy/s and the energy level lifetime of Peak 1 is 980 seconds, it is estimated that Peak 1 reaches saturation at an irradiation dose of approximately 98 Gy. Experimental dose-response measurements for Peak 1 confirm this hypothesis. To enhance the saturation dose for Peak 1, one could use a radiation source with a higher dose rate. For precise measurements of doses below kGy, eliminating Peak 1 and using TL integration after 378 K would be suitable. For measurements of doses above kGy, eliminating both Peak 1 and Peak 2 (with a saturation dose of approximately 2.6 kGy) and using TL integration after 415 K would be appropriate.

G. Repeatability Test

To verify the repeatability of the thermoluminescence signal, the TL curves of $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ phosphor were measured multiple times under 100 Gy irradiation. [Figure 13: see original paper] shows the results of 12 measurements, where the total integral of each TL curve was selected as the outcome and normalized. The experimental results indicate a relative standard error of approximately 0.06% for the measured TL signal. Therefore, TL measurements are minimally affected by radiation and temperature.

IV. CONCLUSION

Y_2 Sm $MgTiO_6$ ($0 \leq x \leq 0.2$) series phosphors were prepared by high-temperature solid-state method. XRD confirmed that Sm^{3+} successfully entered the lattice and replaced Y^{3+}. Photoluminescence measurements revealed four emission peaks at 568 nm, 605 nm, 652 nm, and 715 nm under 409 nm excitation. Analysis of TL curves showed that $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ exhibited the strongest thermoluminescence. Three-dimensional thermoluminescence spectroscopy indicated that the thermoluminescence around 530 K was attributed to the Y_2MgTiO_6 matrix, while the thermoluminescence around 610 K was related to Sm^{3+} defects, also proving that the matrix was less affected by concentration quenching than Sm^{3+}.

The T -T method revealed that the TL spectrum is a superposition of seven peaks. The T values for each overlapping peak are: 384, 419, 449, 532, 581, 610, and 640 K. Additionally, the kinetic order for each peak can be roughly estimated. Utilizing information from three-dimensional thermoluminescence spectroscopy and the T -T method, the TL curve was fitted using the CGCD method, yielding reliable results. The trap parameters corresponding to the seven overlapping peaks are: 0.69, 0.81, 0.91, 1.03, 1.22, 1.29, and 1.49 eV, with energy level lifetimes of 9.8×10^2 s, 2.6×10^4 s, 2.0×10^6 s, 2.0×10^8 s, 3.3×10^{10} s, 6.5×10^{11} s, and 1.8×10^{14} s, respectively.

The saturation dose of $Y_{1\cdot98}Sm_{0\cdot02}MgTiO_6$ sample is 9956 Gy. Notably, this phosphor demonstrates good thermal stability and low production cost, making it suitable for thermoluminescence dosimetry applications in high-dose radiation monitoring. To ensure accurate dose monitoring, dose-response curves were generated for each overlapping peak. Within the 1 kGy range, Peak 1 has already reached saturation (at 102 Gy), while other peaks exhibit linear behavior. For precise measurements of doses below kGy, TL integration after 378 K is recommended. For more accurate measurements of doses above kGy, TL integration after 415 K is preferable.

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