

## ARTICLE

**Effects of Sm Co-doping on Luminescent Properties of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{M}$  ( $\text{M}=\text{Mn}^{4+}$ ,  $\text{Cr}^{3+}$ ) Phosphors**

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The  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{M}$  and doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{M}+\text{Sm}^{3+}$  ( $\text{M}=\text{Mn}^{4+}$ ,  $\text{Cr}^{3+}$ ) phosphors were synthesized by a solid-state reaction method and their luminescent properties were investigated. The results showed that the co-doping of Sm ions did not change the positions of excitation band and emission band but significantly improved the luminescent properties of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}$  phosphors; whereas, the emission intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  was reduced remarkably when Sm ions were co-doped. In addition, a radiative-form energy transfer from  $\text{Sm}^{3+}$  to  $\text{Cr}^{3+}$  was observed for the first time in the Cr, Sm co-doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  phosphors. The results indicated that Sm ions could significantly improve the emission intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}$ , making the  $\text{Sm}^{3+}$ -co-doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}$  phosphor a promising candidate for the applications in display and solid state lightening.

**Key words:** Phosphor, Co-doping, Strontium aluminates, Energy transfer

**I. INTRODUCTION**

In 1996, Nakamura and Fasol in Nichia Company combined a blue LEDs chip with a yellowish phosphor (YAG:Ce) to produce the white light. However, the color rendering index of YAG:Ce phosphor for W-LEDs is too low to be used in warm white LEDs because of lacking a red component (color rendering index ( $\text{CRI}\leq 85$ )) [1]. Recently, the rare earth ions-doped alkali earth aluminates have attracted much attention owing to their high luminescence in blue green to red regions [2, 3], which have been widely used in the illumination, medical instruments, displays, *etc.* Nowadays, the most used activators in the red emitting phosphors are  $\text{Eu}^{2+}$  and  $\text{Eu}^{3+}$ , followed by  $\text{Ce}^{3+}$  and  $\text{Sm}^{3+}$  *etc.* Nevertheless, most of these rare earth ions are very expensive and some chlorides, citrates, and oxides of the above rare earth ions are toxic and harmful, which greatly limits their further applications in W-LEDs. In contrast, the transition-metal ions have lower price but higher luminescence property [4]. In recent years, transition-metal ions-doped strontium aluminates-based phosphors have been found to exhibit high brightness and already applied in some commercial LEDs [5]. A new  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  phosphor has been prepared by high temperature solid state reaction method previously, which showed high

brightness and luminescence chromaticity [6]. However, it was noticeable that the luminescence intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  phosphor was relatively lower and the range of absorption band was not very wide in comparison with those commercial phosphors. Consequently, the  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  phosphor has not been widely applied in W-LEDs.

Energy transfer between rare earth ions or rare earth ions and transition-metal ions has also been regarded as an effective method in improving the luminescent properties of aluminate-based phosphors [7–9]. Luitel *et al.* synthesized  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}+\text{Eu}^{2+}+\text{Dy}^{3+}$  phosphor successfully by combustion method and investigated the optical properties and phosphorescence decays of  $\text{Cr}^{3+}$ -doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  [10]. Kroon *et al.* prepared the phosphors of Ce, Tb co-doped  $\text{LaF}_3$  by hydrothermal method and found that the energy transfer occurred through a non-radiative mechanism [11]. Lin *et al.* investigated the influence of co-doping of different rare earth ions (Dy, Nd, La) on the luminescence of  $\text{CaAl}_2\text{O}_4$ -based phosphors ( $\text{CaAl}_2\text{O}_4:\text{Eu}^{3+}$ ) [12]. Subsequently, researchers found that  $\text{Sm}^{3+}$  ion showed strong emission in variety of lattices in the range from strong yellow to red region [13, 14].

It is known that the emission range of  $\text{Sm}^{3+}$  is overlapped with the excitation range of  $\text{Cr}^{3+}$ , which possibly results in the occurrence of energy transfer between  $\text{Sm}^{3+}$  ions and  $\text{Cr}^{3+}$  ions. Consequently, it is believed that co-doping of  $\text{Cr}^{3+}$  and  $\text{Sm}^{3+}$  will further enhance the photoluminescence properties of strontium aluminate-based phosphors. However, up to now, the effects of co-doping of  $\text{Sm}^{3+}$  on the photoluminescence

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of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{M}$  ( $\text{M}=\text{Mn}^{4+}$ ,  $\text{Cr}^{3+}$ ) phosphors have not been reported. In this work, four kinds of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$ -based phosphors ( $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$ ,  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}+\text{Sm}^{3+}$ ,  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}$  and  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}+\text{Sm}^{3+}$ ) were prepared by solid state reaction method at high temperature and the influences of co-doping of  $\text{Sm}^{3+}$  on the photoluminescence properties of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{M}$  ( $\text{M}=\text{Mn}^{4+}, \text{Cr}^{3+}$ ) were studied by means of XRD, SEM (scanning electron microscopy) and photoluminescence excitation spectra and emission spectra. Furthermore, a feasible energy transfer mechanism from  $\text{Sm}^{3+}$  to  $\text{Cr}^{3+}$  was put forward.

## II. EXPERIMENTS

In this work, samples were synthesized by high temperature solid state reaction. The starting materials include  $\text{MnCO}_3$  (99%),  $\text{Al}_2\text{O}_3$  (99.99%),  $\text{SrCO}_3$  (99%),  $\text{Sm}_2\text{O}_3$  (99.5%),  $\text{Cr}_2\text{O}_3$  (99.5%) and  $\text{H}_3\text{BO}_3$  (99%, as a flux). The molar ratio of  $\text{SrCO}_3$ ,  $\text{Al}_2\text{O}_3$  and  $\text{H}_3\text{BO}_3$  is chosen as 4:7:0.2. The mixing was performed thoroughly with the help of ethanol in agate mortar for 1 h and then preheated at 900 °C in air for 2 h, and finally sintered in a tubular furnace at 1350 °C for 5 h in an oxidizing atmosphere ( $\text{O}_2$  flowing gas).

The crystal phases of phosphors were identified with an X-ray diffractometer (D/MAX2500V). SEM characterization was carried out using a JSM-6490LV SEM instrument. The excitation spectra and emission spectra of the phosphors were measured with a HITACHI F-4500 fluorescence photometer equipped with a 150 W Xe lamp as the excitation source. All the measurements were performed at ambient temperature.

## III. RESULTS AND DISCUSSION

### A. XRD characterization of the prepared phosphors

XRD patterns of the un-doped, 0.1% $\text{Mn}^{4+}$  doped, 0.1% $\text{Cr}^{3+}$  doped, 0.1% $\text{Mn}^{4+}+1.0\%\text{Sm}^{3+}$  co-doped and 0.1% $\text{Cr}^{3+}+1.0\%\text{Sm}^{3+}$  co-doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  phosphors synthesized by conventional solid state reaction method at 1350 °C were presented in Fig.1, respectively. It was shown that single phase of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  (JCPDS card No.52-1876) was obtained and no second phase was detected, implying that the host structure was not significantly changed by the doping of  $\text{Mn}^{4+}$  ions,  $\text{Cr}^{3+}$  and  $\text{Sm}^{3+}$  ions.  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  was reported to crystallize in an orthorhombic crystal structure with  $Pmma$  space group [15] in which octahedral sites ( $\text{AlO}_6$ ) and tetrahedral sites ( $\text{AlO}_4$ ) are embodied, as shown in Fig.2. According to the differences of ionic radii, it can be deduced that  $\text{Mn}^{4+}$  and  $\text{Cr}^{3+}$  ions have a pronounced tendency to occupy the  $\text{Al}^{3+}$  positions in  $\text{AlO}_6$  octahedra, and  $\text{Sm}^{3+}$  ions tend to occupy the  $\text{Sr}^{2+}$  sites in the

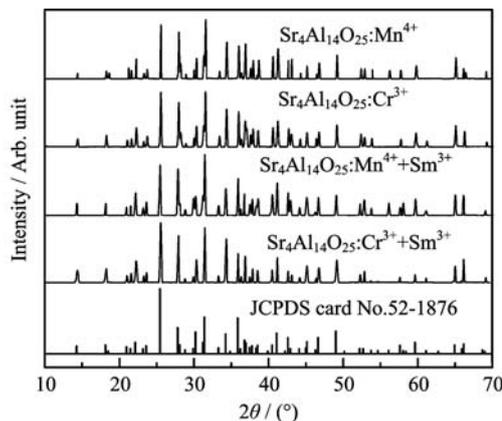


FIG. 1 XRD patterns of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Mn}^{4+}$ ,  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Cr}^{3+}$ ,  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Mn}^{4+}+1.0\%\text{Sm}^{3+}$ , and  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Cr}^{3+}+1.0\%\text{Sm}^{3+}$  compared with the standard  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  (JCPDS card No.52-1876).

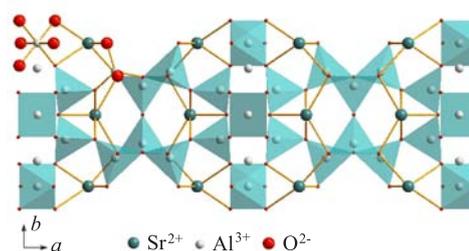


FIG. 2 Projection of the structure of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  on the (001) plane.

$\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  (see Fig.2), even though it will cause a little charge imbalance effect.

### B. SEM characterization of the prepared phosphors

SEM images of the  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{M}+\text{Sm}^{3+}$  ( $\text{M}=\text{Mn}^{4+}$ ,  $\text{Cr}^{3+}$ ) samples are shown in Fig.3. It was shown that the phosphor sample prepared with 0.1% $\text{Mn}^{4+}$  consisted of irregular shape particles with an average size of 2.5  $\mu\text{m}$  (Fig.3(a)). By contrast, the particles in the sample prepared with 0.1% $\text{Cr}^{3+}$  were somewhat homogeneous in grain size (Fig.3(b)). However, it should be noted that there are little or indistinct differences in grain sizes and morphologies when  $\text{Sm}^{3+}$  ions or  $\text{Cr}^{3+}$  ions were co-doped into the above samples.

### C. Photoluminescence properties of $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}+\text{Sm}^{3+}$ phosphor

Figure 4 shows the excitation spectra and emission spectra of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}$  phosphors. For the excitation band, 420 and 567 nm could be ascribed to

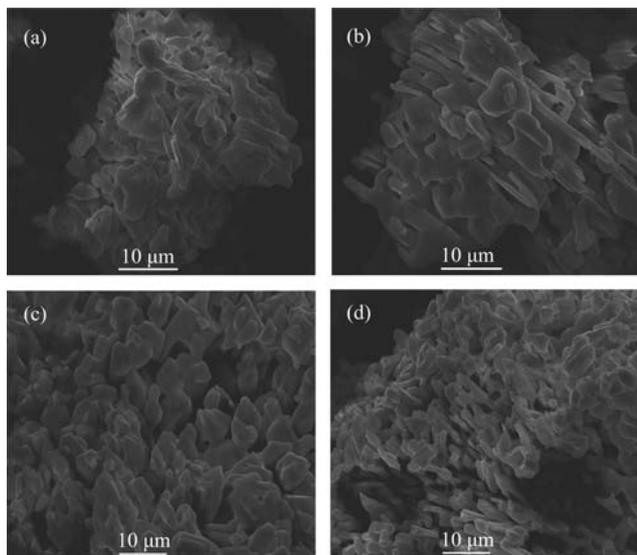


FIG. 3 SEM images of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>-based phosphors with (a) 0.1%Mn<sup>4+</sup>, (b) 0.1%Cr<sup>3+</sup>, (c) 0.1%Mn<sup>4+</sup>+1.0%Sm<sup>3+</sup>, (d) 0.1%Cr<sup>3+</sup>+1.0%Sm<sup>3+</sup>.

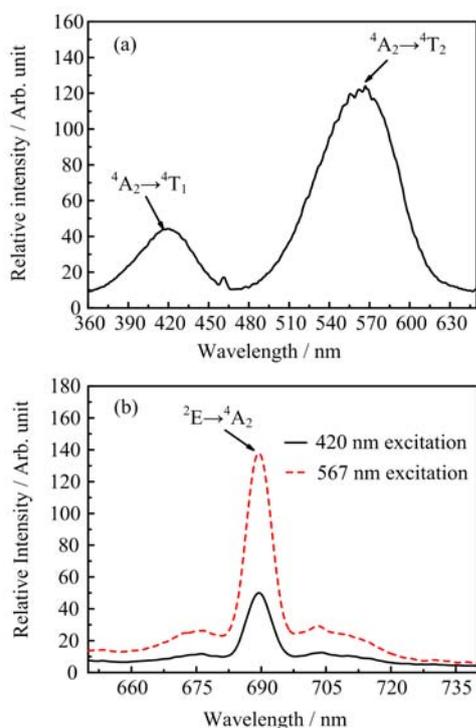


FIG. 4 (a) Excitation spectrum at 689 nm and (b) emission spectra at 420 and 567 nm of 0.1%Cr<sup>3+</sup>-doped Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>.

the transition of <sup>4</sup>A<sub>2</sub>→<sup>4</sup>T<sub>1</sub> and <sup>4</sup>A<sub>2</sub>→<sup>4</sup>T<sub>2</sub>, respectively. For its emission band, the main peak was located at 689 nm which was in the deep red region and could be ascribed to a typical emission of Cr<sup>3+</sup> [16]. However, its emission intensity under the excitation band from 360 nm to 460 nm was relatively weak, implying that

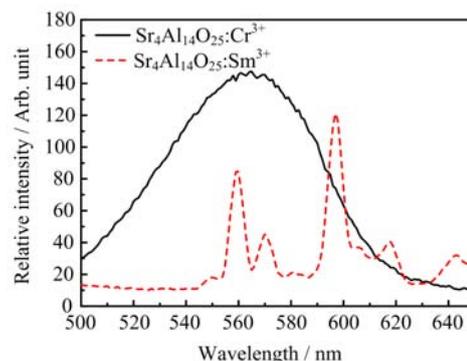


FIG. 5 Spectra overlap of single-doped Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub> with Cr<sup>3+</sup> or Sm<sup>3+</sup>.

Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup> phosphor could not be effectively excited by an UV-light and blue light. Therefore, the ions which would efficiently transfer its energy to Cr<sup>3+</sup> were very important in improving the application feasibility of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup> phosphor.

For the previously reported Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Sm<sup>3+</sup> [17], it was shown that the Sm<sup>3+</sup> could be excited by 365 and 420 nm. Thus, Cr<sup>3+</sup> with red emission could be incorporated in the same host crystal. Therefore, it is reasonable to investigate the effect of co-doping of Sm<sup>3+</sup> ions and Cr<sup>3+</sup> ions on the photoluminescence of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub> phosphors. It can be found from Fig.5 and Fig.6 that both Cr<sup>3+</sup>-doped and Sm<sup>3+</sup>-doped Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub> phosphors could be excited by 415 nm light. Moreover, the co-doping of Sm<sup>3+</sup> ions and Cr<sup>3+</sup> ions did not change the positions and shapes of luminescence band of phosphors. Noticeably, the emission intensity of Cr<sup>3+</sup> ions was greatly enhanced, whereas the emission intensity of Sm<sup>3+</sup> ions was greatly reduced. That meant there was an energy transfer process from Sm<sup>3+</sup> ions to Cr<sup>3+</sup> ions, which resulted in the enhancement effect in the co-doped phosphors.

As far as the so-called energy transfer processes in the co-doped phosphors are concerned, resonance transfer and radiative transition have been regarded as two primary mechanisms in this system. Through the energy levels of Sm<sup>3+</sup> and Cr<sup>3+</sup> we can deduce that the resonance transfer is impossible between Cr<sup>3+</sup> and Sm<sup>3+</sup> owing to the level mismatch. In fact, the enhancement effect is mostly likely related to the radiative transition process in the Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup>+Sm<sup>3+</sup> system. It is apparent that spectral overlap can be readily found between the emission band of Sm<sup>3+</sup> ions and the excitation spectrum of Cr<sup>3+</sup> ions (see Fig.5), implying that a radiative energy transfer possibly occurs from the Sm<sup>3+</sup> ions to the doped Cr<sup>3+</sup> ions. In other words, it can be reasonably deduced that Sm<sup>3+</sup> ions can absorb the energy and emit lights at wavelengths of 560, 570, and 597 nm, and then the emitted lights are reabsorbed by Cr<sup>3+</sup> ions and thus a red light at 689 nm is emitted. Nowadays, radiative transition is to some ex-

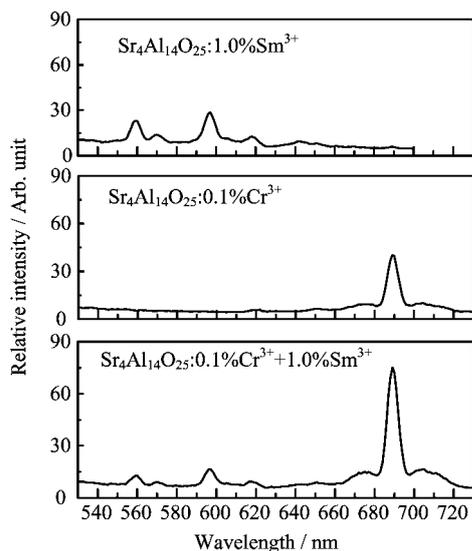


FIG. 6 The emission spectra at  $\lambda_{\text{ex}}=415$  nm of single doped  $\text{Cr}^{3+}$ ,  $\text{Sm}^{3+}$  ions and co-doping in  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$ .

tent believed to be an efficient method to enhance the photoluminescence property of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}+\text{Sm}^{3+}$  system though there is some energy loss, which has been revealed by some literatures, such as the radiative transition from  $\text{Mn}^{2+}$  to  $\text{Cr}^{3+}$  in the  $\text{MgAl}_2\text{O}_4$  system [18] and the inner energy transfer from the host to  $\text{Eu}^{3+}$  ions in  $\text{CaGa}_2\text{O}_4:\text{Eu}^{3+}$  [19].

In addition, the influence of the concentration of  $\text{Sm}^{3+}$  ions on the emission intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Cr}^{3+}+x\%\text{Sm}^{3+}$  phosphor is shown in Fig.7. It is shown that the luminescence intensity was the greatest when the concentration of the doped  $\text{Sm}^{3+}$  ions is 1.0%. With any further increment of  $\text{Sm}^{3+}$  concentration, the emission intensity decreased owing to the concentration quenching effect. Therefore, the optimum concentration of  $\text{Sm}$  ions in  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Cr}^{3+}+x\%\text{Sm}^{3+}$  system was 1.0%.

#### D. Photoluminescence properties of co-doping $\text{Cr}^{3+}$ and $\text{Sm}^{3+}$ in $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$

Since the co-doping of  $\text{Sm}^{3+}$  could effectively improve the emission intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Cr}^{3+}$ , it is worth knowing whether  $\text{Sm}^{3+}$  has the similar effects on the luminescent properties of  $\text{Mn}^{4+}$  doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  phosphor or not. In order to make it clear, we tentatively prepared  $\text{Sm}^{3+}$  and  $\text{Mn}^{4+}$  co-doped phosphor. The excitation spectrum and emission spectrum of 0.1% $\text{Mn}$ -doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  are shown in Fig.8. It could be seen that the excitation spectrum of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  was attributed to the transitions of  ${}^4\text{A}_2\rightarrow{}^4\text{T}_1$  (300 nm to 400 nm) and  ${}^4\text{A}_2\rightarrow{}^4\text{T}_2$  (400 nm to 450 nm) of  $\text{Mn}^{4+}$  ions, and emission peak which was located at 651 nm were ascribed to the transition of  ${}^2\text{E}\rightarrow{}^4\text{A}_2$  of  $\text{Mn}^{4+}$

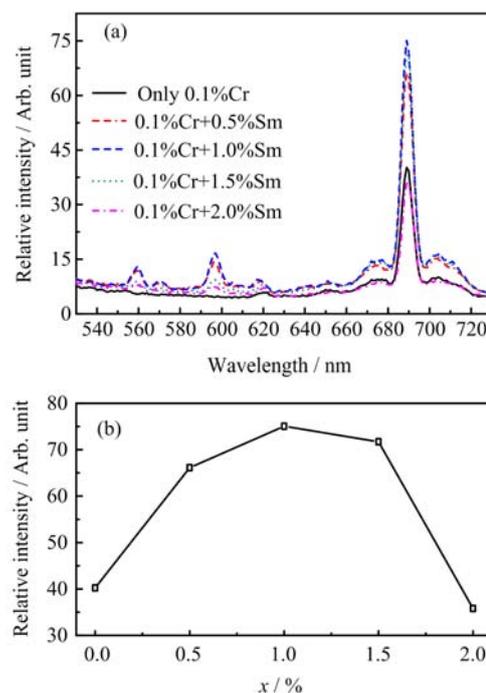


FIG. 7 (a) The emission spectra at  $\lambda_{\text{ex}}=415$  nm of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Cr}^{3+}+x\%\text{Sm}^{3+}$  and (b) the variation of relative intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:0.1\%\text{Cr}^{3+}+x\%\text{Sm}^{3+}$  with different concentration of  $\text{Sm}^{3+}$ .

ions. Obviously, the results were highly close to the previous investigations [6].

The photoluminescence properties of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}+\text{Sm}^{3+}$  are shown in Fig.9. What was unexpected was that the co-doping of  $\text{Sm}^{3+}$  ions decreased the emission intensity of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  dramatically, while the photoluminescence band position of the phosphor was not altered. In fact, it was noticeable that there was no overlapping between the luminescence spectra of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}$  and those of  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Sm}^{3+}$ , which was apparently different from  $\text{Cr}^{3+}$ -doped and  $\text{Sm}^{3+}$ -doped  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  phosphors. Therefore, it could also be deduced that there was little energy transfer process from  $\text{Sm}^{3+}$  ions to  $\text{Mn}^{4+}$  ions in the  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Mn}^{4+}+\text{Sm}^{3+}$  phosphor.

In addition, it can be deduced from the radii of  $\text{Mn}^{4+}$  ions that  $\text{Mn}^{4+}$  ions had tendencies to occupy the sites of  $\text{Al}^{3+}$  ions in  $\text{Al}-\text{O}$  octahedra ( $\text{AlO}_6$ ) in  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  and thus led to the charge imbalance (*i.e.*, an extra positive charge was produced). Simultaneously, a  $\text{Sr}^{2+}$  vacancy (two negative charges) was generated correspondingly to keep the overall charge balance of crystal. It is worth noticing that a  $\text{Sr}^{2+}$  vacancy can be generated more easily in comparison with the  $\text{Al}^{3+}$  vacancy in  $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$  because the bond energy of  $\text{Sr}-\text{O}$  is lower than that of  $\text{Al}-\text{O}$  bond. By contrast,  $\text{Sm}^{3+}$  ions tended to occupy the positions of  $\text{Sr}^{2+}$  ions and thus extra  $\text{Sr}^{2+}$  vacancies (two negative charges) were

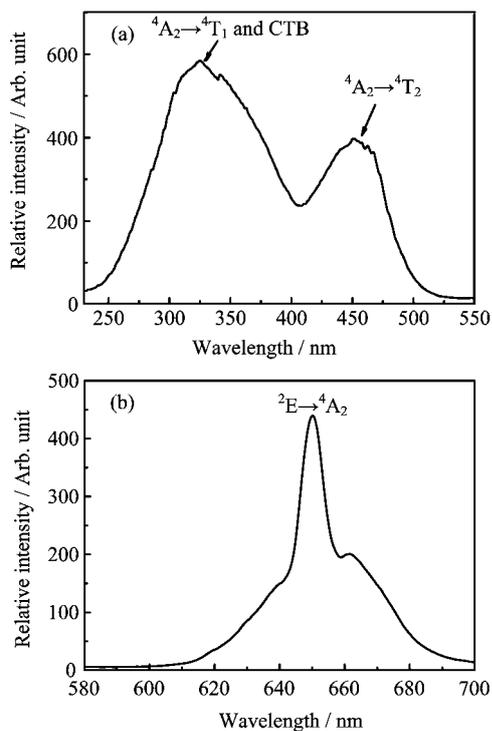


FIG. 8 (a) Excitation spectrum monitored at 651 nm, and (b) emission spectra excited by 325 nm light of 0.1%Mn<sup>4+</sup>-doped Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>.

induced to keep the charge balance when Sm<sup>3+</sup> ions were co-doped into Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Mn<sup>4+</sup> phosphors, which deteriorated the charge imbalance in Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub> and thus had a remarkably negative effect on the luminescent properties of phosphor.

### E. Luminescence chromaticity

To evaluate the chromaticity properties of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup>+Sm<sup>3+</sup>, and Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Mn<sup>4+</sup>+Sm<sup>3+</sup> we calculated chromaticity coordinates and presented CIE chromaticity diagram, which are shown in Fig.10. It was found that the chromaticity coordinate of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup>+Sm<sup>3+</sup> was close to that of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup> in deep red region. In contrast, the chromaticity coordinate of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Mn<sup>4+</sup>+Sm<sup>3+</sup> was in the lower saturated red region compared with that of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Mn<sup>4+</sup>. In addition, it could be seen that the chromaticity (*x*, *y*) of the prepared red phosphor Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup>+Sm<sup>3+</sup> was 0.728956 and 0.271038, which was close to that of commercial 3.5MgO·0.5MgF<sub>2</sub>·GeO<sub>2</sub>:Mn<sup>4+</sup> phosphor. Apparently, the prepared Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup>+Sm<sup>3+</sup> phosphor could enlarge the deep red region and improve the rendering index. Consequently, it could be concluded that Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup>+Sm<sup>3+</sup> is suitable to be used as a high efficient red phosphor in W-LEDs.

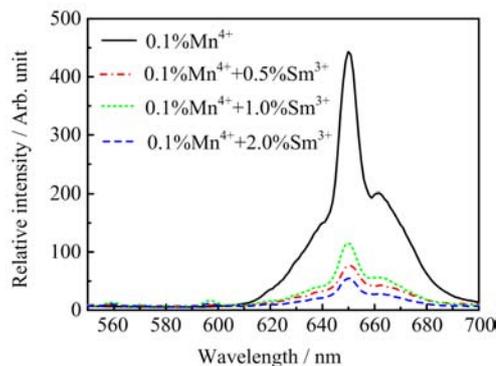


FIG. 9 Dependence of emission spectra of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Mn<sup>4+</sup>+Sm<sup>3+</sup> phosphor on the concentrations of Sm<sup>3+</sup> ions excited by a 325 nm light.

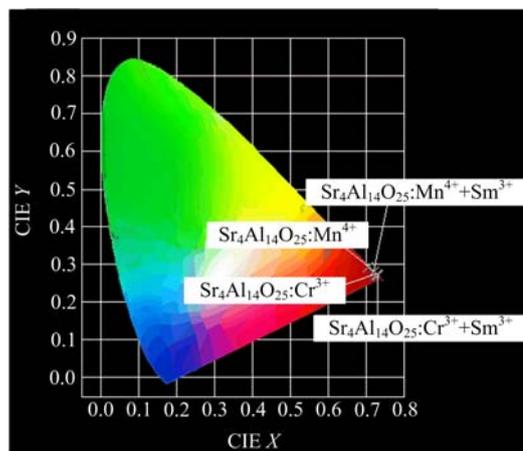


FIG. 10 CIE chromaticity diagram of different phosphors.

### IV. CONCLUSION

The Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:M and Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:M+Sm<sup>3+</sup> (M=Mn<sup>4+</sup>, Cr<sup>3+</sup>) phosphors were synthesized by solid-state reaction method at 1350 °C for 5 h in the air. It was found that the excitation and emission band positions were not altered and the emission intensity was significantly enhanced when Sm<sup>3+</sup> ions were co-doped in Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup> phosphors, which was mainly ascribed to the radiation and reabsorption process from Sm<sup>3+</sup> ions to Cr<sup>3+</sup> ions. In contrast, the emission intensity of Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Mn<sup>4+</sup> was reduced remarkably when Sm<sup>3+</sup> ions were co-doped. Based on the chromaticity coordinates and CIE chromaticity diagram of the prepared phosphors, we believed that the Sm<sup>3+</sup>-doped Sr<sub>4</sub>Al<sub>14</sub>O<sub>25</sub>:Cr<sup>3+</sup> phosphors showed promising applications in displays and solid state lightening.

## V. ACKNOWLEDGMENTS

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