

## Synthesis of $\text{NaLa}(\text{MoO}_4)_2$ : $\text{Ho}^{3+}/\text{Yb}^{3+}$ Upconversion Phosphors via Microwave Sol-Gel Route and Their Spectroscopic Properties

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**Abstract:**  $\text{NaLa}_{1-x}(\text{MoO}_4)_2$ : $\text{Ho}^{3+}/\text{Yb}^{3+}$  phosphors with the correct doping concentrations of  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  were successfully synthesized by the microwave-modified sol-gel method. Well-crystallized particles formed after heat-treatment at 800°C for 16 h showed a fine and homogeneous morphology with particle sizes of 3-5  $\mu\text{m}$ . Under excitation at 980 nm, the UC intensities of the doped samples exhibited strong yellow emissions based on the combination of strong emission bands at 545-nm and 655-nm emission bands in green and red spectral regions, respectively. The strong 545-nm emission band in the green region corresponds to the  $^5\text{S}_2/^5\text{F}_4 \rightarrow ^5\text{I}_8$  transition in  $\text{Ho}^{3+}$  ions, while the strong emission 655-nm band in the red region appears due to the  $^5\text{F}_5 \rightarrow ^5\text{I}_8$  transition in  $\text{Ho}^{3+}$  ions. The spectroscopic properties were examined comparatively using photoluminescence emission and Raman spectroscopy evaluated in detail.

**Key words:** Upconversion, Microwave sol-gel, Double molybdate, Raman spectroscopy

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### Introduction

Recently, design and synthesis for lanthanide activated photoluminescence particles have attracted considerable attention in their applications, such as fluorescent lamps, cathode ray tubes, solid-state laser, amplifiers for fiber optics communication and new optoelectronic devices, which show high luminescence quantum yields, since usually more than one metastable excited state exists and multiple emissions are observed [1-3]. Rare-earth doped upconversion (UC) particles can convert near infrared radiation of low energy into visible radiation of high energy. The synthesis and the luminescence properties of UC particles have evolved in their applications, since they are considered as potentially active components in new optoelectronic devices and luminescent labels for imaging and biodetection assays, which overcome the current limitations in traditional photoluminescence materials [4-6].

Most of  $\text{NaLn}(\text{MoO}_4)_2$  ( $\text{Ln} = \text{La}^{3+}, \text{Gd}^{3+}, \text{Y}^{3+}$ ) possess the tetragonal scheelite structure with the space group  $I4_{1/a}$ , and belong to the family of double molybdates compounds. It

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is stable for the structure of  $\text{NaLn}(\text{MoO}_4)_2$  to be transformed to the tetragonal scheelite structure from the monoclinic structure. It is possible for the trivalent rare earth ions in the tetragonal phase to be partially substituted by  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  ions. The  $\text{Yb}^{3+}$  ion, as a sensitizer, can be dramatically excited by an incident light source energy. This energy is transferred to the activator from which radiation can be emitted. The  $\text{Ho}^{3+}$  ion activator is the luminescence center of the UC particles, while the sensitizer enhances the UC luminescence efficiency [7-9].

For preparation of the double molybdate  $\text{NaLn}(\text{MoO}_4)_2$ , several processes have been developed via specific preparation processes [10-15]. Microwave heating is delivered to the material surface by radiant and/or convection heating, which heat energy is transferred to the bulk of the material via conduction [16]. It is a cost-effective method that provides high homogeneity and is easy to scale-up, and it is emerging as a viable alternative approach for the quick synthesis of high-quality luminescent materials.

In this study,  $\text{NaLa}_{1-x}(\text{MoO}_4)_2:\text{Ho}^{3+}/\text{Yb}^{3+}$  phosphors with the correct doping concentrations of  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  ( $x = \text{Ho}^{3+} + \text{Yb}^{3+}$ ,  $\text{Ho}^{3+} = 0.05$  and  $\text{Yb}^{3+} = 0.35, 0.40, 0.45$  and  $0.50$ ) were successfully prepared by the microwave sol-gel method, followed by heat treatment. The synthesized particles were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). Pump power dependence and Commission Internationale de L'Éclairage (CIE) chromaticity of the UC emission intensity were evaluated in detail. The optical properties were examined comparatively using photoluminescence (PL) emission and Raman spectroscopy.

## Experimental

In this study, precise amounts of  $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$  (99%, Sigma-Aldrich, USA),  $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$  (99%, Sigma-Aldrich, USA),  $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$  (99%, Alfa Aesar, USA),  $\text{Ho}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$  (99.9%, Sigma-Aldrich, USA),  $\text{Yb}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$  (99.9%, Sigma-Aldrich, USA), citric acid (99.5%, Daejung Chemicals, Korea),  $\text{NH}_4\text{OH}$  (A.R.), ethylene glycol (A.R.) and distilled water were used to prepare  $\text{NaLa}(\text{MoO}_4)_2$ ,  $\text{NaLa}_{0.6}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$ ,  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$ ,  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  compounds with the correct doping concentrations of  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  ( $\text{Ho}^{3+} = 0.05$  and  $\text{Yb}^{3+} = 0.35, 0.40, 0.45$  and  $0.50$ ). To prepare  $\text{NaLa}(\text{MoO}_4)_2$ , 0.2 mol%  $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$  and 0.114 mol%  $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$  were dissolved in 20 mL of ethylene glycol and 80 mL of 5M  $\text{NH}_4\text{OH}$  under vigorous stirring and heating. Subsequently, 0.4 mol%  $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$  and citric acid were dissolved in 100 mL of distilled water under vigorous stirring and heating. The molar ratio of citric acid to total metal ions was 2:1. Then, the solutions were mixed together vigorously and heated at 80-100°C. Finally, highly transparent solutions were obtained and adjusted to pH=7-8 by the addition of  $\text{NH}_4\text{OH}$  or citric acid. To prepare  $\text{NaLa}_{0.6}(\text{MoO}_4)_2:\text{Ho}_{0.05}/\text{Yb}_{0.35}$ , the mixture of 0.24 mol%  $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ , 0.14 mol%  $\text{Yb}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$  and 0.02 mol%  $\text{Ho}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$  was used for creation of the solution containing the rare-earth elements. To prepare  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}/\text{Yb}_{0.40}$ , the solution containing the rare-earth elements was employed using 0.22 mol%  $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ , and 0.02 mol%

Ho(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O and 0.16 mol% Yb(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O. To prepare NaLa<sub>0.50</sub>(MoO<sub>4</sub>)<sub>2</sub>:Ho<sub>0.05</sub>/Yb<sub>0.45</sub>, the mixture of 0.20 mol% La(NO<sub>3</sub>)<sub>3</sub>·6H<sub>2</sub>O, 0.02 mol% Ho(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O and 0.18 mol% Yb(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O and was used for the creation of the solution containing the rare-earth elements. To prepare NaLa<sub>0.45</sub>(MoO<sub>4</sub>)<sub>2</sub>:Ho<sub>0.05</sub>/Yb<sub>0.50</sub>, the solution containing the rare-earth elements was generated using 0.18 mol% La(NO<sub>3</sub>)<sub>3</sub>·6H<sub>2</sub>O, and 0.02 mol% Ho(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O and 0.2 mol% Yb(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O. The transparent solutions were placed into a microwave oven operating at a frequency of 2.45 GHz with a maximum output-power of 1250 W for 30 min. The working cycle of the microwave reaction was controlled very precisely using a regime of 40 s on and 20 s off for 15 min, followed by further treatment of 30 s on and 30 s off for 15 min. The samples were treated with ultrasonic radiation for 10 min to produce a light yellowish transparent sol. After this, the light yellowish transparent sols were dried at 120°C in a dry oven to obtain black dried gels. The black dried gels were ground and heat-treated at 800°C for 16 h at 100°C intervals between 600-800°C. Finally, white particles were obtained for pure NaLa(MoO<sub>4</sub>)<sub>2</sub> and pink particles were obtained for the doped compositions.

The phase composition of the synthesized particles was identified using XRD (D/MAX 2200, Rigaku, Japan). The microstructure and surface morphology of the synthesized particles were observed using SEM (JSM-5600, JEOL, Japan). The PL spectra were recorded using a spectrophotometer (Perkin Elmer LS55, UK) at room temperature. Pump power dependence of the UC emission intensity was measured at levels of working power from 20 to 110 mW. Raman spectra measurements were performed using a LabRam Aramis (Horiba Jobin-Yvon, France) with the spectral resolution of 2 cm<sup>-1</sup>. The 514.5-nm line of an Ar ion laser was used as an excitation source; the power on the samples was kept at 0.5 mW level to avoid the sample's decomposition.

## Results and Discussion

Fig. 1 shows XRD patterns of the (a) JCPDS 24-1103 pattern of NaLa(MoO<sub>4</sub>)<sub>2</sub>, the synthesized (b) pure NaLa(MoO<sub>4</sub>)<sub>2</sub>, (c) NaLa<sub>0.60</sub>(MoO<sub>4</sub>)<sub>2</sub>:Ho<sub>0.05</sub>Yb<sub>0.35</sub>, (d) NaLa<sub>0.55</sub>(MoO<sub>4</sub>)<sub>2</sub>:Ho<sub>0.05</sub>Yb<sub>0.40</sub>, (e) NaLa<sub>0.50</sub>(MoO<sub>4</sub>)<sub>2</sub>:Ho<sub>0.05</sub>Yb<sub>0.45</sub> and (f) NaLa<sub>0.45</sub>(MoO<sub>4</sub>)<sub>2</sub>:Ho<sub>0.05</sub>Yb<sub>0.50</sub> particles. It was possible to assign almost all of the XRD peaks indexed to pure tetragonal phase, which can be mostly consistent with the standard data of NaLa(MoO<sub>4</sub>)<sub>2</sub> (JCPDS 24-1103). NaLa(MoO<sub>4</sub>)<sub>2</sub> as a member of double molybdate family has a sheelite structure with the lattice constants of a=5.344 Å and c=11.730 Å, which is tetragonal with space group I4<sub>1/a</sub>. It can be observed, that the diffraction peaks of the doped samples of Fig. 1(c)-(f) shift slightly to the high angle compared to that of pure sample of Fig. 1(b). In the crystal structure of NaLa<sub>1-x</sub>(MoO<sub>4</sub>)<sub>2</sub>, the La<sup>3+</sup> ion site is supposed to be occupied by Ho<sup>3+</sup> and Yb<sup>3+</sup> ions with fixed occupations according to the nominal chemical formulas. The defined crystal structure contains MoO<sub>4</sub> tetrahedrons coordinated by four (La/Ho/Yb)O<sub>8</sub> square antiprisms through the common O ions. In the doped crystals, the unit cell shrinkage results from the substitution of La<sup>3+</sup> ions by Ho<sup>3+</sup> and Yb<sup>3+</sup> ions. It is assumed that the radiuses of Ho<sup>3+</sup> (R=1.015 Å) and Yb<sup>3+</sup> (R=0.985 Å) are smaller than that of La<sup>3+</sup> (R=1.16 Å), when the coordination number is CN = 8 [17]. Consequently, it should be emphasized that the Ho<sup>3+</sup> and Yb<sup>3+</sup> ions can be

effectively doped in the  $\text{NaLa}_{1-x}(\text{MoO}_4)_2$  lattice by partial substitution of  $\text{La}^{3+}$  site, which leads to the unit cell shrinkage due to the similar radii of  $\text{La}^{3+}$  and by partial substitution of  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  while maintaining the tetragonal structure of the  $\text{NaLa}_{1-x}(\text{MoO}_4)_2$ .

Fig. 2 provides SEM images of the synthesized (a)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$  and (b)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles. The as-synthesized samples are well crystallized with a fine and homogeneous morphology and particle size of 3-5  $\mu\text{m}$ . The samples have no discrepancy in aspect of morphological feature, and agglomerated particles induced by the inter-diffusions among the grains. It should be noted that the doping concentrations for  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  have no effects on the morphological feature. The microwave sol-gel method of the double molybdates provides the energy to synthesize the bulk of the material uniformly, so that fine particles with controlled morphology can be fabricated in a short time period. The method is a cost-effective way to fabricate highly homogeneous products with easy scale-up and is a viable alternative for the rapid synthesis of UC particles. This suggests that the microwave sol-gel route is suitable for the creation of homogeneous  $\text{NaLa}_{1-x}(\text{MoO}_4)_2:\text{Ho}^{3+}/\text{Yb}^{3+}$  crystallites.

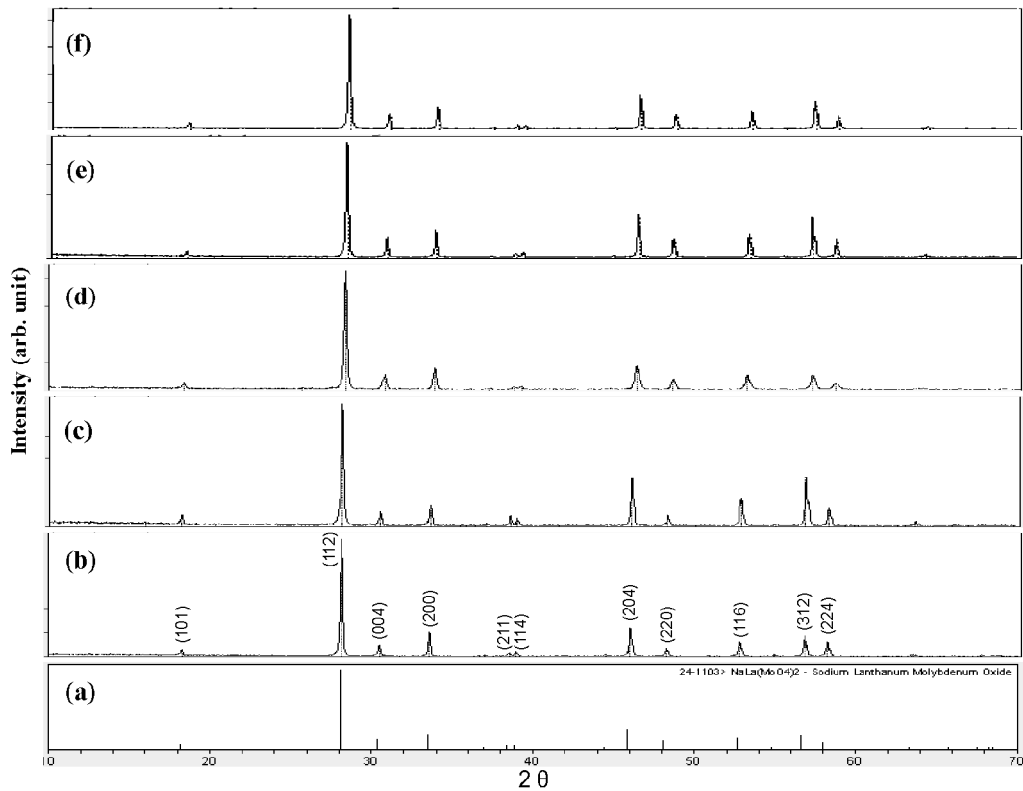
Fig. 3 shows the UC photoluminescence emission spectra of (a)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$ , (b)  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$ , (c)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and (d)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles excited under 980 nm at room temperature. The doped samples exhibited strong yellow emissions based on the combination of strong emission bands at 545-nm and 655-nm emission bands in green and red spectral regions, respectively. The strong 545-nm emission band in the green region corresponds to the  $^5\text{S}_2/{}^5\text{F}_4 \rightarrow {}^5\text{I}_8$  transition in  $\text{Ho}^{3+}$  ions, while the strong 655-nm emission band in the red region appears due to the  ${}^5\text{F}_5 \rightarrow {}^5\text{I}_8$  transition in  $\text{Ho}^{3+}$  ions. The  $\text{Ho}^{3+}$  ion activator is the luminescence center for these UC particles, and the  $\text{Yb}^{3+}$  sensitizer dramatically enhances the UC luminescence efficiency. The UC intensity is dependent on the  $\text{Yb}^{3+}:\text{Ho}^{3+}$  ratio in samples (a) 7:1, (b) 8:1, (c) 9:1 and (d) 10:1. The higher intensity of (c)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  caused the ratio of  $\text{Yb}^{3+}:\text{Ho}^{3+}$  to be 9:1, whereas the higher contents of the  $\text{Yb}^{3+}$  ion, used as a sensitizer owing to its strong absorption at around 980 nm, can remarkably enhance the UC luminescence through energy transfer.

The logarithmic scale dependence of the UC emission intensities at 545 and 655 nm on the working pump power over the range of 20 to 110 mW in the  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  sample is shown in Fig. 4. In the UC process, the UC emission intensity is proportional to the slope value  $n$  of the irradiation pumping power, where  $n$  is the number of pumped photons required to produce UC emission [18]:

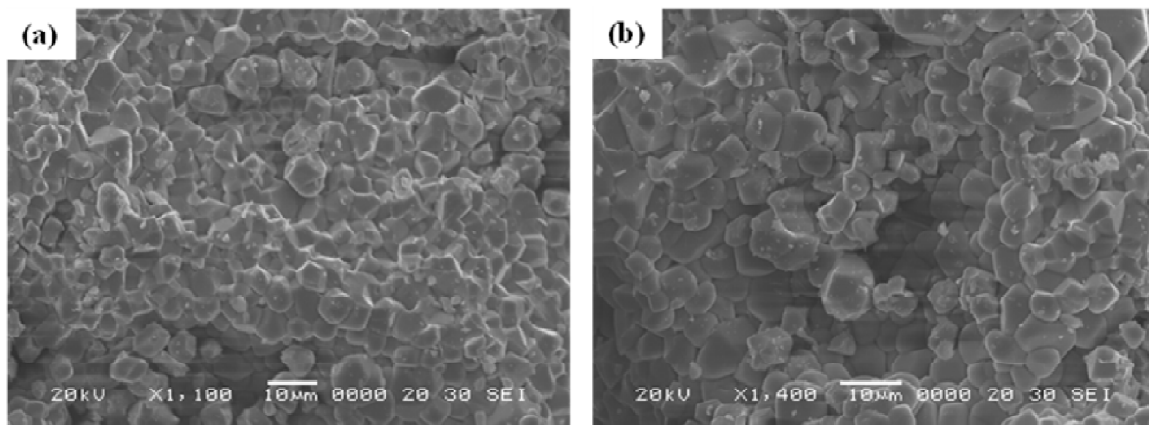
$$I \propto P^n \quad (1)$$

$$\text{Ln}I \propto n \text{Ln}P \quad (2)$$

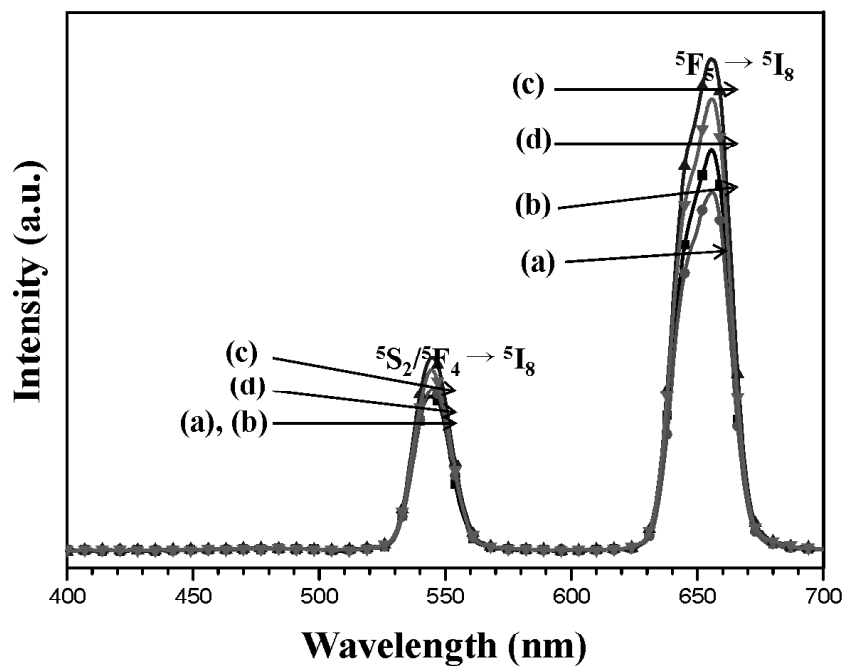
Where value  $n$  is the number of the pumped photons required to excite the upper emitting state,  $I$  is the UC luminescent intensity and  $P$  is the laser pumping power. The calculated slope values  $n$  in Fig. 4 indicate slope  $n = 1.87$  for green emission at 545 nm; this value is 1.91 for red emission at 655 nm.



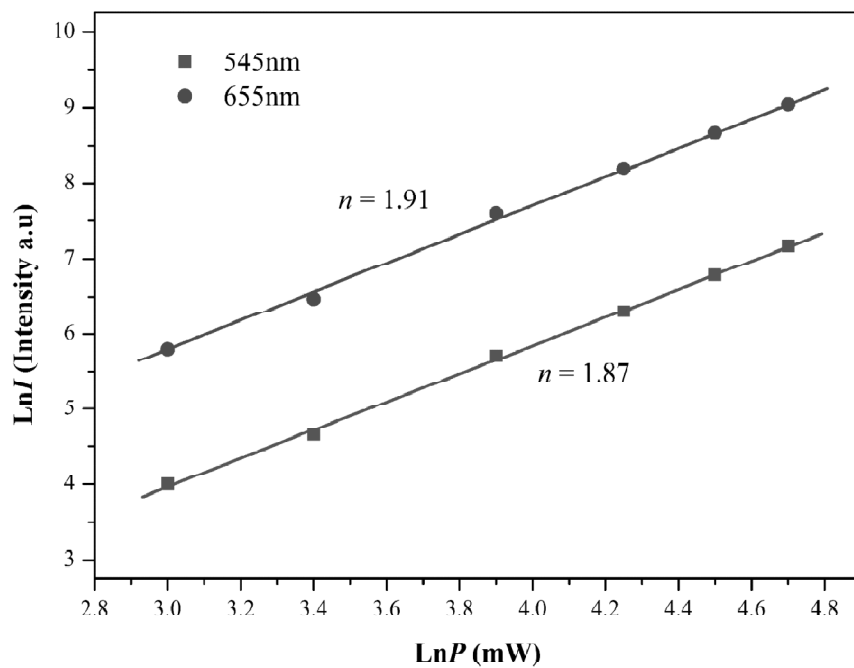
**Figure 1:** X-ray diffraction patterns of the (a) JCPDS 24-1103 pattern of  $\text{NaLa}(\text{MoO}_4)_2$ , the synthesized (b) pure  $\text{NaLa}(\text{MoO}_4)_2$ , (c)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$ , (d)  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$ , (e)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and (f)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles



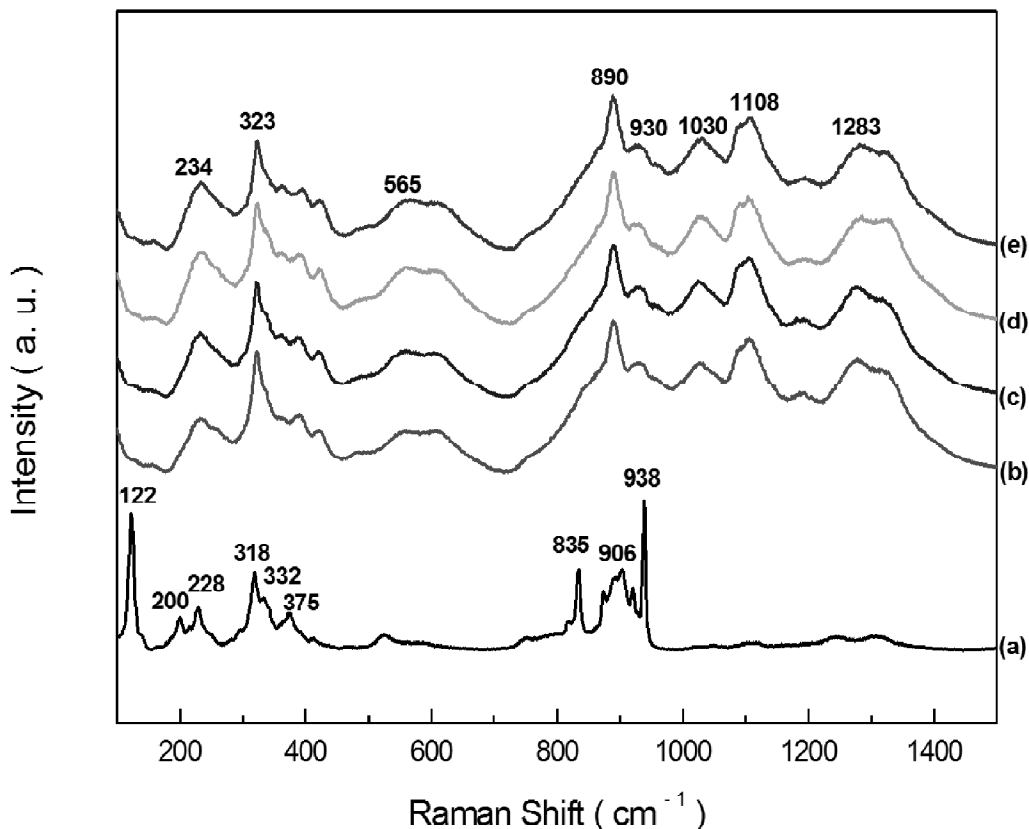
**Figure 2:** Scanning electron microscopy images of the synthesized (a)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$  and (b)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles



**Figure 3:** Upconversion photoluminescence emission spectra of (a)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$  (b)  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$  (c)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and (d)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles excited under 980 nm at room temperature



**Figure 4:** Logarithmic scale dependence of the upconversion emission intensity on the pump power in the range from 20 to 110 mW at 545 and 655 nm in the  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  sample



**Figure 5:** Raman spectra of the synthesized (a) pure  $\text{NaLa}_2(\text{MoO}_4)_2$  (b)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$  (c)  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$ , (d)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and (e)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles excited by the 514.5-nm line of an Ar ion laser at 0.5 mW

The Raman spectra recorded from the (a) pure  $\text{NaLa}(\text{MoO}_4)_2$ , (b)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$ , (c)  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$ , (d)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and (e)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles samples under the 514.5 nm excitation are shown in Fig. 5. The internal modes for the (a) pure  $\text{NaLa}(\text{MoO}_4)_2$  particles were detected at lower frequencies of 200, 228, 318, 332 and 375  $\text{cm}^{-1}$  and at higher frequencies of 835, 906 and 938  $\text{cm}^{-1}$ . The well-resolved sharp peaks for the  $\text{NaLa}(\text{MoO}_4)_2$  indicate a high crystallinity state of the synthesized particles. The Raman spectra of (b)  $\text{NaLa}_{0.60}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.35}$ , (c)  $\text{NaLa}_{0.55}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.40}$ , (d)  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  and (e)  $\text{NaLa}_{0.45}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.50}$  particles samples indicate the very strong and dominant peaks at lower frequencies of 234, 323 and 565  $\text{cm}^{-1}$  and at higher frequencies of 890, 930, 1030, 1108 and 1283  $\text{cm}^{-1}$ . Consequently, these strong yellow phosphors of  $\text{NaLa}_{1-x}(\text{MoO}_4)_2$  doped with  $\text{Ho}^{3+}/\text{Yb}^{3+}$  lead to high emitting efficiency and superior thermal and chemical stability, and these materials, which can overcome the current limitations of traditional photoluminescence materials, can be considered potentially active components in new optoelectronic devices.

## Conclusions

UC  $\text{NaLa}_{1-x}(\text{MoO}_4)_2:\text{Ho}^{3+}/\text{Yb}^{3+}$  phosphors with the correct doping concentrations of  $\text{Ho}^{3+}$  and  $\text{Yb}^{3+}$  were successfully synthesized via the microwave sol-gel route. Well-crystallized particles formed after heat-treatment at  $800^\circ\text{C}$  for 16 h showed a fine and homogeneous morphology with particle sizes of 3-5  $\mu\text{m}$ . Under excitation at 980 nm, the UC doped particles exhibited yellow emissions based on a strong 545-nm emission band in the green region and a very strong 655-nm emission band in the red region, which were assigned to the  $^5\text{S}_2/{}^5\text{F}_4 \rightarrow {}^5\text{I}_8$  and  ${}^5\text{F}_5 \rightarrow {}^5\text{I}_8$  transitions, respectively. The higher intensity of  $\text{NaLa}_{0.50}(\text{MoO}_4)_2:\text{Ho}_{0.05}\text{Yb}_{0.45}$  provided that the ratio of  $\text{Yb}^{3+}:\text{Ho}^{3+}$  would be 9:1, whereas the higher contents of  $\text{Yb}^{3+}$  ion as a sensitizer owing to its strong absorption around 980 nm can remarkably enhance the UC luminescence through energy transfer. The calculated slope values  $n$  indicate slope  $n = 1.87$  for green emission at 545 nm; this value is 1.91 for red emission at 655 nm. This result indicates the achievement of attractive yellow UC emissions for use potentially active components in new optoelectronic devices and luminescent devices.

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