Yellow Emission Obtained by Combination of Broadband Emission and Multi-Peak Emission in Garnet Structure Na$_2$YMg$_2$V$_3$O$_{12}$: Dy$^{3+}$ Phosphor

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Abstract: The fabrication and luminescent performance of novel phosphors Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ were investigated by a conventional solid-state reaction method. Under near-UV light, the Na$_2$YMg$_2$V$_3$O$_{12}$ host self-activated and released a broad emission band (400–700 nm, with a peak at 524 nm) ascribable to charge transfer in the (VO$_4$)$_3^{3-}$ groups. Meanwhile, the Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ phosphors emitted bright yellow light within both the broad emission band of the (VO$_4$)$_3^{3-}$ groups and the sharp peaks of the Dy$^{3+}$ ions at 490, 582, and 663 nm at a quenching concentration of 0.03 mol. The emission of the as-prepared Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ phosphors remained stable at high temperatures. The obtained phosphors, commercial Y$_2$O$_3$:Eu$^{3+}$ red phosphors, and BaMgAl$_{10}$O$_{17}$:Eu$^{2+}$ blue phosphors were packed into a white light-emitting diode (WLED) device with a near-UV chip. The designed WLED emitted bright white light with good chromaticity coordinates (0.331, 0.361), satisfactory color rendering index (80.2), and proper correlation to a color temperature (7364 K). These results indicate the potential utility of Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ phosphor as a yellow-emitting phosphor in solid-state illumination.

Keywords: Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$; yellow emitting; luminescence; WLED

1. Introduction

For several years, phosphor-converted white light-emitting diodes (pc-WLEDs) have been recognized as the most promising replacements of traditional incandescent and fluorescence lamps [1–5]. These solid-state light sources deliver high luminescence efficiency and an excellent operation lifetime (>10,000 h) while conserving energy and lowering the pollution risk. Most commercial pc-WLEDs are obtained by two methods [6,7]. One method generates white light by combining yellow phosphors with blue LED chips, such as the yellow phosphor YAG: Ce$^{3+}$ [8,9]. However, the absence of the red-emitting component reduces the quality of the white light, yielding poor color reproduction and a low color rendering index (Ra) [10]. The other method stimulates blue, green, and red (RGB) phosphors by violet or ultraviolet light LEDs [11]. Although this method improves the Ra and can tune the correlated color temperature (CCT), the emission efficiency is limited by reabsorption among the different phosphors [1,12]. The different thermal stabilities and ageing rates of the various phosphors also restrict their applications in WLEDs [13]. Therefore, high-performance single-phased...
phosphors that can be excited by ultraviolet (UV) or near-UV (n-UV) light are urgently needed [14–16]. A single-host white-emitting phosphor must usually have a broad emission peak or multiple emission peaks in the visible region. Therefore, searching for new broadband emission or multi-peak emission phosphors is significant for improving the color stability and service life of WLEDs excited by UV or n-UV light [17,18].

In recent decades, the rare earth luminescent materials have been used in many fields, such as lighting, photosynthesis enhancement, and photodynamic activation for cancer treatments [19–21]. Broad emission peaks or multiple emission peaks in the visible region facilitate white light emission with appropriate Ra and CCT values [22–24]. Vanadate composed of VO₄³⁻ tetrahedrons is an important non-rare earth ion-doped luminescent material displaying broadband emission, excellent luminous efficiency, and good chemical stability [25,26]. For example, A₃(VO₄)₂ (A = Mg, Sr, Ba) phosphors yield intense charge transfer (CT) absorption bands in the n-UV region and broad emission bands covering 400–700 nm. Further studies have reported that when doped with rare earth ions, vanadate is a good host material that enhances the emission efficiency of phosphors [27,28]. Guo et al. reported that Eu³⁺-activated Ba₂BiV₃O₁₁ phosphors are promising candidates for red-emitting phosphors in WLEDs, as they efficiently convert UV light from 394 nm onwards into red light [29]. Bright orange-red emission has been obtained by doping Sm³⁺ in NaSrVO₄ phosphor under n-UV light excitation [30]. Song et al. [17] studied self-activated NaₓYMg₂V₃O₁₂ vanadate phosphors, and reported a broad emission band of 400–700 nm centered at 520 nm. However, the red emission intensity was relatively low, below the requirements of white light emission. Dy³⁺ doping should broaden the emission band of NaₓYMg₂V₃O₁₂ phosphors.

In this work, a series of yellow-emitting NaₓYMg₂V₃O₁₂:Dy³⁺ phosphors was prepared by a conventional high-temperature solid-state method. The phase purities, micromorphologies, luminescence properties, and decay times of the as-prepared NaₓYMg₂V₃O₁₂:Dy³⁺ phosphors were studied in detail. The suitability of the yellow-emitting phosphors for indoor illumination was demonstrated in a WLED device incorporating the developed phosphors.

2. Results and Discussion

The phase compositions and crystal structures of the as-prepared powder samples were characterized at room temperature. The XRD patterns of NaₓYMg₂V₃O₁₂:xDy³⁺ (x = 0, 0.005, 0.01, 0.03, 0.05, 0.07) samples exhibited main peaks at 17.5°, 20.3°, 28.8°, 32.3°, 33.9°, 35.5°, 36.9°, 51.0°, 53.2°, and 55.4° (Figure 1a), corresponding, respectively, to the (2 1 1), (2 2 0), (4 0 0), (4 2 0), (3 3 2), (4 2 2), (4 3 1), (4 4 4), (6 0 4), and (6 4 2) facets of a single garnet structure with a cubic Ia₃d (No. 230) space group. All diffraction peaks of the NaₓYMg₂V₃O₁₂:Dy³⁺ samples were well matched with the standard profile (PDF No.49-0412), confirming that doping with Y³⁺ ions did not significantly affect the crystalline structure of NaₓYMg₂V₃O₁₂.

Figure 1b shows the spatial structure of the unit cell of the garnet-structured NaₓYMg₂V₃O₁₂. As implied, the A sites were occupied by alkaline metal ions Na⁺ and rare earth ions Y³⁺, which were coordinated with eight oxygen O²⁻ ions to form a dodecahedron with D₄ symmetry (without an inverse center). The alkaline-earth metal Mg²⁺ ions located in the octahedral sites B bonded with six oxygen atoms, and the metal ion V⁵⁺ (in VO₄³⁻) occupied the T₄ sites and were surrounded by four O²⁻ ions. As Y³⁺ and Dy³⁺ have similar cationic radii and the same valence, the Y³⁺ ions in the host lattice were easily replaced by Dy³⁺ ions with no structural transformation. The XRD patterns of NaₓYMg₂V₃O₁₂:Dy³⁺ match those of the standard card, further confirming that the Dy³⁺ ions doped in the NaₓYMg₂V₃O₁₂ host had replaced the Y³⁺ sites.

The microscopic morphology, particle size, and grain shape of a phosphor are important factors in applications. Field emission scanning electron microscopy (FESEM) images of the NaₓYMg₂V₃O₁₂:0.03Dy³⁺ sample confirmed that all particles were irregular oblate spheres with an average particle size of 1 µm (Figure 1c). The spherical morphology was similar to that of commercial YAG:Ce³⁺ phosphor, which possesses the same garnet structure. The average particle size
of the prepared phosphor was also similar to that of commercial phosphors. This size may enhance the dispersion and transparency of phosphors in the glue when packaging with the WLEDs.

![Figure 1](image-url)  

**Figure 1.** (a) XRD patterns of Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ phosphors and the standard profile (Pdf NO. 49-0412), (b) schematic of the crystal structure of Na$_2$YMg$_2$V$_3$O$_{12}$, and (c) FESEM micrograph of the Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ phosphor.

The photoluminescence (PL) and PL emission (PLE) spectra of the undoped Na$_2$YMg$_2$V$_3$O$_{12}$ sample are presented in Figure 2a–c. Na$_2$YMg$_2$V$_3$O$_{12}$ shows a broad absorption band of 250–400 nm, matching the absorption of near-UV chips in WLEDs. When excited at 289 nm and 365 nm, the as-prepared particles also emitted a broad emission band, ranging from 400 to 700 nm with a maximum at 524 nm. This emission was attributed to the CT of an electron from the 2p orbital of oxygen to the vacant 3d orbital of V$^{5+}$ in the tetrahedral (VO$_4$)$_3^{3-}$ groups [31,32]. The emission band centered at 524 nm was decomposed into two sub-bands by Gaussian peak separation, one centered at 289 nm (4.30 eV), the other at 365 nm (3.41 eV) [33]. As shown in Figure 2d, the (VO$_4$)$_3^{3-}$ group has a ground state $^1A_1$ and excited states $^1T_1$, $^1T_2$, $^3T_1$, and $^3T_2$. The decomposed emission sub-bands were attributed to $^3T_2\rightarrow^1A_1$ (Em1 = 512 nm (2.43 eV)) and $^3T_1\rightarrow^1A_1$ (Em2 = 571 nm (2.18 eV)) transitions of the (VO$_4$)$_3^{3-}$ groups, respectively. The excitation band was also composed of two sub-bands, which were assigned to the $^1A_1\rightarrow^1T_2$ (Ex1 = 4.30 eV) and $^1A_1\rightarrow^1T_1$ (Ex2 = 3.41 eV) transitions of the (VO$_4$)$_3^{3-}$ groups.
with n-UV LED chips.

The broad excitation spectrum indicates that the excitation pathways of Dy\(^{3+}\) luminescence depend on the excitation wavelength. When excited at 289 nm and 365 nm, the Dy\(^{3+}\) emission was mainly caused by Dy-O CT and by energy transfer from the absorption of V-O CT, respectively \([12,34]\). Monitoring the phosphor emission under 582 nm, the broad excitation band from 250 to 400 nm (which peaks at two sites: 289 nm and 365 nm) resembles the excitation spectrum of non-doped Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\). This may have resulted from the energy transfer behavior from Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\) to Dy\(^{3+}\) ions, which completely overlaps the excitation spectrum of Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(^{3+}\) at room temperature. The broad emission band at 524 nm was attributed to \(\text{Dy}^{3+}\) emissions changed because the excitation pathways of Dy\(^{3+}\) luminescence depend on the excitation wavelength. When excited at 289 nm and 365 nm, the Dy\(^{3+}\) emission was mainly caused by Dy-O CT and by energy transfer from the absorption of V-O CT, respectively \([12,34]\). Monitoring the phosphor emission under 582 nm, the broad excitation band from 250 to 400 nm (which peaks at two sites: 289 nm and 365 nm) resembles the excitation spectrum of non-doped Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\). This may have resulted from the energy transfer behavior from Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\) to Dy\(^{3+}\) ions, which completely overlaps the excitation spectrum of Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(^{3+}\) ions. The broad excitation spectrum indicates that the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(^{3+}\) sample can be efficiently excited under n-UV light, and can be well matched with n-UV LED chips.

The PL spectra of Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(^{3+}\) \((x = 0, 0.005, 0.01, 0.03, 0.05, 0.07)\) samples with different doping concentrations are shown in Figure 3b,c. As the Dy\(^{3+}\) concentration increased, the intensities of the emission peaks increased to a maximum at \(x = 0.03\), and then decreased under the concentration quenching effect \([35]\). To investigate the cause of concentration quenching, the interaction type between two excitations was calculated by the following formula:

\[
\frac{I}{x} = \frac{k}{1 + \beta x^{Q/3}} \quad (1)
\]

Figure 3a shows the PLE (\(\lambda_{\text{em}} = 582\) nm) and PL (\(\lambda_{\text{ex}} = 289\) and 365 nm) spectra of the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):0.03Dy\(^{3+}\) samples, (b), (c), and (d) PLE and PL spectra of the samples after Gaussian peak separation. (e) Schematic of the excitation and emission processes of (VO\(_4\))\(^3−\) tetrahedrons in vanadate phosphor.

Figure 2. (a) Photoluminescence (PL) and PL emission (PLE) spectra of the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\) samples, (b), (c), and (d) PLE and PL spectra of the samples after Gaussian peak separation. (e) Schematic of the excitation and emission processes of (VO\(_4\))\(^3−\) tetrahedrons in vanadate phosphor.
where $k$ and $\beta$ are constants, $I$ is the emission intensity, and $Q$ represents the interaction type. When $Q$ is 3, 6, 8, and 10, the interactions are exchange, dipole–dipole, dipole–quadrupole, and quadrupole–quadrupole interactions, respectively. The $Q$ value was obtained by linear fitting of the relationship between $\log(I/x)$ and $\log(x)$. When the phosphors were excited at 289 and 365 nm, the slopes $(-Q/3)$ were determined as $-0.995$ and $-0.968$, respectively (Figure 3d). Both $Q$ values were close to the theoretical value of 3.0, indicating that at higher concentrations, the intensity of the Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ phosphors was quenched by exchange interactions. The excitation spectra of Na$_2$YMg$_2$V$_3$O$_{12}$:xDy$^{3+}$ monitored at 582 nm were also optimized at $x = 0.03$ (Figure 3e). The CIE (International Commission on illumination) chromaticity coordinates of the Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ sample were determined as (0.357, 0.461) (Figure 3f). The yellow light emission was the combination of the self-activated emission of the Na$_2$YMg$_2$V$_3$O$_{12}$ host with the dominant 4f–4f transitions of the Dy$^{3+}$ ion [36].

Figure 3. (a) PLE and PL spectra of the Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ sample. Emission spectra at (b) $\lambda_{ex} = 289$ nm and (c) $\lambda_{ex} = 365$ nm for different concentrations of Dy$^{3+}$ in Na$_2$YMg$_2$V$_3$O$_{12}$:xDy$^{3+}$. (d) Linear fitting data of $\log(I/x)$ versus $\log(x)$ for the Na$_2$YMg$_2$V$_3$O$_{12}$:xDy$^{3+}$ phosphors. (e) Excitation spectra ($\lambda_{em} = 582$ nm) of Na$_2$YMg$_2$V$_3$O$_{12}$:xDy$^{3+}$. (f) CIE chromaticity coordinates of the Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ sample.
To understand the behaviors of the synthesized compounds, the Na₂YMg₂V₃O₁₂∶xDy³⁺ phosphors were excited at 289 and 365 nm, and their PL decay curves were recorded at 582 nm. The results are shown in Figure 4. The decay curves of Na₂YMg₂V₃O₁₂∶xDy³⁺ were well fitted to the following exponential function [37]:

\[ I_t = A e^{-\frac{t}{\tau}} + I_0 \] (2)

where \( I_t \) and \( I_0 \) are the emission intensities at time \( t \) and the initial time, respectively, and \( A \) is a constant. \( \tau \) determines the decay time. The average lifetimes of the Na₂YMg₂V₃O₁₂∶xDy³⁺ phosphors with \( x = 0, 0.005, 0.01, 0.03, 0.05, \) and \( 0.07 \) were determined as 1.60, 1.58, 1.54, 1.48, 1.42, and 1.44 \( \mu s \), respectively, at \( \lambda_{ex} = 289 \) nm, and as 1.53, 1.52, 1.49, 1.50, 1.41, and 1.40 \( \mu s \), respectively, at \( \lambda_{ex} = 365 \) nm. The PL lifetimes of the Na₂YMg₂V₃O₁₂∶xDy³⁺ were similar under both excitation wavelengths, possibly reflecting the similar energy transfer behaviors between the vanadate host and Dy³⁺.

![Figure 4](image_url)

**Figure 4.** Decay curves of Na₂YMg₂V₃O₁₂∶xDy³⁺ with different concentrations of Dy³⁺ excited at (a) \( \lambda_{ex} = 289 \) nm and (b) \( \lambda_{ex} = 365 \) nm, \( (\lambda_{em} = 582 \) nm).

High thermal resistance of phosphors is very important for practical applications in solid-state lighting, as it ensures high optical performance of the WLED device. The thermal quenching performance of Na₂YMg₂V₃O₁₂∶0.03Dy³⁺ phosphor was assessed from the temperature-dependent emission spectra under excitation at 289 and 365 nm. As shown in Figure 5a,c, the emission intensity reduced smoothly as the temperature increased, because the probability of non-radiative transitions increases at higher temperatures. As shown in the insets of Figure 5a,c, the PL integral intensities at 100 °C were 61.6% \( (\lambda_{ex} = 289 \) nm) and 61.48% \( (\lambda_{ex} = 365 \) nm) of their room temperature intensities. However, the emission positions in the temperature-dependent emission spectra were relatively robust to temperature changes.

To further investigate the thermal stability of this phosphor, the activation energy \( (\Delta E) \) of Na₂YMg₂V₃O₁₂∶0.03Dy³⁺ was calculated by the Arrhenius equation [38]:

\[ I(T) = \frac{I_0}{1 + c e^{-\frac{\Delta E}{kT}}} \] (3)

where \( I_0 \) is the emission intensity of the phosphor at room temperature, \( I(T) \) is the temperature-dependent intensity, \( c \) is a constant, and \( k \) is the Boltzmann constant \( (8.629 \times 10^{-5} \text{ eV K}^{-1}) \). From the slopes of the \( \ln[I_0/I(T) - 1] \) versus \( 1/kT \) plots (Figure 5b,d), which were well fitted to Equation (3), the \( \Delta E \)s were determined as 0.21 and 0.26 eV under excitation at 289 and 365 nm, respectively. Table 1 compares the CIE chromaticity coordinates, CCT and lifetimes of Na₂YMg₂V₃O₁₂∶0.03Dy³⁺, and other Dy³⁺-doped phosphors [39–41]. The obtained Na₂YMg₂V₃O₁₂∶Dy³⁺ phosphors presented relatively high thermal stability and are potentially applicable to WLEDs.
Table 1. Comparison of CIE chromaticity coordinates (x, y), correlated color temperature (CCT) (K), and lifetimes (μs) of Dy$^{3+}$-doped phosphors.

| Sample                          | (x, y)       | CCT  | Lifetimes | Reference |
|---------------------------------|--------------|------|-----------|-----------|
| Na$_2$YMg$_2$V$_3$O$_{12}$: Dy$^{3+}$ | (0.357, 0.461) | 4288 | 1.50      | Present work |
| Sr$_3$Y$_2$(BO$_3$)$_4$: Dy$^{3+}$ | (0.300, 0.314) | 5896 | -         | [42]       |
| KBaY(MoO$_4$)$_3$: Dy$^{3+}$    | (0.431, 0.457) | 3988 | 0.125     | [43]       |
| Na$_3$Gd(VO$_4$)$_2$:Dy$^{3+}$  | (0.664, 0.335) | -   | 0.234     | [22]       |
| Ca$_3$TeO$_6$:Dy$^{3+}$        | (0.417, 0.460) | 3730 | 0.506     | [35]       |
| NaLa(PO$_3$)$_4$: Dy$^{3+}$    | (0.292, 0.336) | -   | 0.78      | [44]       |
| NaCaPO$_4$:Dy$^{3+}$           | (0.32, 0.37)  | 5962 | 0.604     | [45]       |

Figure 5. (a,c): PL spectra of the Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ phosphor at different temperatures (25–175 °C) excited at $\lambda_{ex}$ = 289 and 365 nm, respectively. Insets show the PL intensities of Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ as functions of temperature. (b,d): Linear fitting curves of ln[I$_0$/I(T) − 1] versus 1/kT for the Na$_2$YMg$_2$V$_3$O$_{12}$:0.03Dy$^{3+}$ phosphor excited at 582 and 365 nm, respectively.

To further prove the feasibility of the as-prepared phosphors in solid-state illumination, we designed and packaged WLED devices based on an n-UV chip (365 nm) and the Na$_2$YMg$_2$V$_3$O$_{12}$:Dy$^{3+}$ phosphors. To compensate for the color combination imbalance and improve the Ra of the LEDs, we added small amounts of commercial Y$_2$O$_3$:Eu$^{3+}$ red phosphors and BaMgAl$_{10}$O$_{17}$:Eu$^{2+}$ blue phosphors, thereby fabricating a warm white-emitting LED. Figure 6 shows the electroluminescence spectra and
photographs of the as-fabricated LED devices. Obviously, after adding the red and blue phosphors, the emission light of the LED device changed from yellow to white. The CIE coordinates, \( R_a \) value, and CCT of the white light generated from the LED device (Figure 6c) were (0.331, 0.361), 80.2, and 7364 K, respectively. The CIE chromaticity coordinates of the LED device are also given in Figure 7. The fabricated device yielded a warm white light. The results demonstrate that the as-prepared phosphors are promising yellow-emitting phosphors for indoor solid-state illumination.

3. Materials and Methods

The \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:x\text{Dy}^{3+} \) (\( x = 0, 0.005, 0.01, 0.03, 0.05, 0.07 \)) phosphors were prepared through a solid state reaction method. The analytical reagent \( \text{Mg(OH)}_2 \) (average particle size, \( d_{50} \approx 3.798 \mu m \), excess \( \text{NaHCO}_3 \) was needed to compensate for the volatilization loss. The raw materials were mixed thoroughly in agate mortar for 30 min and then put into a crucible with a lid. These mixed chemicals were mixed with barium magnesium aluminum \( \text{O}_{17} : \text{Eu}^{2+} \) and high pure rare earth oxides \( \text{Y}_2\text{O}_3 : \text{Eu}^{3+} \). The samples were incorporated into 365 nm InGaN LED chips with an injunction current.

Figure 6. Electroluminescence (EL) spectra (left) and photographs (right) of (a) \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:0.03\text{Dy}^{3+} \), (b) \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:0.03\text{Dy}^{3+} \) with \( \text{BaMgAl}_{10}\text{O}_{17}:\text{Eu}^{2+} \), and (c) \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:0.03\text{Dy}^{3+} \) with \( \text{BaMgAl}_{10}\text{O}_{17}:\text{Eu}^{2+} \) and \( \text{Y}_2\text{O}_3 : \text{Eu}^{3+} \). The samples were incorporated into 365 nm InGaN LED chips with an injunction current.

Figure 7. CIE coordinates of LEDs fabricated with (a) \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:0.03\text{Dy}^{3+} \), (b) \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:0.03\text{Dy}^{3+} \) and \( \text{BaMgAl}_{10}\text{O}_{17}:\text{Eu}^{2+} \), and (c) \( \text{Na}_2\text{YMg}_2\text{V}_3\text{O}_{12}:0.03\text{Dy}^{3+} \), \( \text{BaMgAl}_{10}\text{O}_{17}:\text{Eu}^{2+} \), and \( \text{Y}_2\text{O}_3 : \text{Eu}^{3+} \) phosphors.
When excited by near-UV light, the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\) with CIE coordinates, color rendering index, and CCT of (0.331, 0.361), 80.2, and 7364 K, respectively. The phosphor powder was heated with a heating rate of 50 \(^\circ\)C/min, and held at each test temperature for 3 min. The PL decay curves were obtained through a spectrofluorometer (TBX-PS; HORIBA Jobin Yvon, Paris, France) monitoring at 593 nm under excitations of 289 nm and 365 nm, respectively. The electroluminescence spectra, CCT, and Ra of the packed LED devices were measured using a UV-vis-near IR spectrophotocolorimeter (PMS-80, Everfine, Hangzhou, China).

4. Conclusions

In summary, a series of vanadate phosphors Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(_{3+}\) was synthesized by the conventional solid-state reaction method at 800 \(^\circ\)C for 6 h. In the XRD analysis, the as-prepared phosphors were found to crystallize in a single garnet structure with a cubic Ia3d (230) space group. When excited by near-UV light, the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\) host was self-activated and emitted a broad emission band of 400–700 nm with a peak at 524 nm. This emission was ascribed to CT in the (VO\(_4\))\(_{3-}\) groups. Meanwhile, the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(_{3+}\) phosphors showed both the broadband luminescence of the (VO\(_4\))\(_{3-}\) groups and the sharp peak emissions of Dy\(_{3+}\) ions, and emitted intense yellow light. The phosphors were also excited by light at 289 and 365 nm, and the optimum Dy\(_{3+}\) concentration was around 0.03 mol. The temperature-dependent emission spectra indicated high thermal stability of the Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}\):Dy\(_{3+}\) phosphors. Finally, a WLED device based on n-UV chip, Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}:0.03\text{Dy}^{3+}, \text{Y}_{2}O_{3}:\text{Eu}^{3+},\) and BaMgAl\(_{10}\)O\(_{17}:\text{Eu}^{2+}\) presented an intense white light with CIE coordinates, color rendering index, and CCT of (0.331, 0.361), 80.2, and 7364 K, respectively. These results suggest the suitability of Na\(_2\)YMg\(_2\)V\(_3\)O\(_{12}:\text{Dy}^{3+}\) phosphor as a yellow-emitting phosphor in WLEDs.

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**Sample Availability:** Samples of the compounds are available from the authors.