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Optical properties of white and muti-color light emitting diodes

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ABSTRACT

$BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors are used to emit blue, green and red emissions under excitation from a violet light emitting diode (LED), respectively. White and multi-color LEDs have been generated by mixing a violet emission from a violet LED and blue, green and red emissions from the $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors. The optical properties of white and multi-color LED are discussed.

Key words : white LED, muti-color LED

Introduction

Major developments in wide band gap Ⅲ-Ⅴ nitride compound semiconductors have led to the commercial production of high-efficiency light emmitting diodes (LEDs) (1, 2). Traditional colored LEDs are widely used in devices such as indicator lights and traffic lights. Blue InGaN technology makes possible the two-band white LED in which white light is obtained by coating $Y_3Al_5O_{12}$: Ce phosphor onto a blue LED chip (3, 4). White light is generated by additive color mixing of blue emission from the blue LED and yellow emission from the $Y_3Al_5O_{12}$: Ce phosphor. White LED has a number of advantages over incandescent and halogen lamps in power efficiency and long lifetime. However, two-band white LED with low color rendering index cannot express an actual nature-color, expecially in the red region.

In order to improve color properties of the white LED, multi-band white LED should be fabricated by using muti-color emitting phosphor or mixing of various color emitting phosphors. Tricolor was generated from $Ba_3MgSi_2O_8$: Eu^{2+}, Mn^{2+} phosphor with near-UV LED (5). However, this phosphor has a weak blue emission. To generate the muti-color white LED pumped by near-UV LED, the combination of ZnS: Ag (blue), ZnS: Cu,Al (green), and ZnCdS: Ag (red) phophors was used (6). $SrGa_2S_4$: Eu (green) / ZnCdS: Ag,Cl (red) systems was also used to generate the three-band white LED using a blue LED (7). The white LED of employing blue, green, and red emitting phosphors excited by a near UV LEDs can offer a higher efficiency solid-state lightening. Therefore, it is important to search for excellent blue, green, and red emitting multi-phases phosphors that can be excited efficiently under near UV range around 400 nm. In this paper, we present the optical properties of white and muti-color LED by using $BaMg_2Al_{16}O_{27}$: Eu (blue), $SrGa_2S_4$: Eu (green), and SrY_2S_4: Eu (red) phosphors from a violet LED.

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Experimental

Blue emitting $BaMg_2Al_{16}O_{27}$: Eu^{2+} phosphor was obtained from Kasei Opt. Ltd. Green emitting $SrGa_2S_4$: Eu^{2+} phosphor was synthesized by heating 0.95 mmol of strontium sulfide (SrS), 2.0 mmol of gallium dimethyldithiocarbomate ($Ga[(CH_3)_2NCS_2]_3$), 0.05 mmol of the europium complex ($[(CH_3)_4N]Eu[(CH_3)_2NCS_2]_4$), and excess sulfur for 2 hours at 850 °C (8). Red emitting SrY_2S_4: Eu^{2+} phosphor was prepared by solid-state reaction with 0.98 mmol $SrCO_3$, 2.0 mmol Y_2CO_3, 0.02 mmol of Eu_2CO_3, and appropriate amount of Na_2CO_3 as a flux at 1300 °C for 8 hours in H_2S steam (9).

Photoluminescent excitation and emission measurements were carried out using a spectrum analyzer (DARSA, PSI) with 0.275 m grating monochromator with an Acton Research Co., PHV400 photomultiplier tube, and a 500 W Xe lamp as an excitation source. The incident beam was perpendicular to the surface of the sample, and the observation angle was 45° to the excitation source. A commercial SMD-type violet LED (λ_{max} =405 nm) was used. $BaMg_2Al_{16}O_{27}$: Eu (blue), $SrGa_2S_4$: Eu (green), and/or SrY_2S_4: Eu (red) phosphor suspensions were coated onto the surface of the SMD-type violet LED. The suspensions was made by dispersing a phosphor in poly-vinyl-alcohol (polymerization degree: 200).

Results and Discussion

Fig 1 shows photoluminescent excitation and emission spectra of $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors. The excitation spectra show that $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors have strong absorptions at 405 nm, which is an emission wavelength of the violet LED used. $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors emit blue (450 nm), green (535 nm), and red (640 nm) under 405 nm excitation, respectively. Therefore, $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu are suitable as blue, green, and red emitting phosphors under excitation from the violet LED.

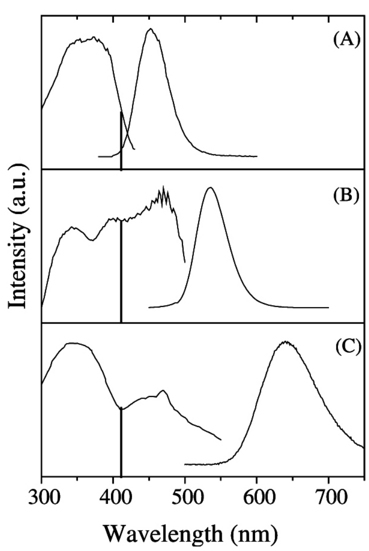

Fig 1. Excitation and emission spectra of (A) $BaMg_2Al_{16}O_{27}$:Eu, (B) $SrGa_2S_4$:Eu, and (C) SrY_2S_4:Eu phosphors. The bar at 405 nm corresponds to wavelength of the violet LED.

Fig 2(A) shows the photoluminescence spectra of violet and blue emitting LEDs where only $BaMg_2Al_{16}O_{27}$: Eu phosphor is coated on a violet LED. The two distinct emission peaks appear at 405 nm and 450 nm which are the wavelengths of the violet LED and blue emission from the only $BaMg_2Al_{16}O_{27}$: Eu phosphor, respectively. When the amounts of $BaMg_2Al_{16}O_{27}$: Eu phosphor is increased, the intensity of the 405 nm emission decreases, while that of the 450 nm emission increases simultaneously. The CIE (Commission International de l'Eclairage) chromaticity coordinates of the photoluminescence spectra of violet and blue emitting LEDs are shown in Fig 3(A). The CIE chromaticity coordinates of a violet LED are x=0.17 and y=0.01. As the concentration of $BaMg_2Al_{16}O_{27}$: Eu phosphor is increased, CIE chromaticity coordinates approach those of the pure blue emitting $BaMg_2Al_{16}O_{27}$: Eu phosphor with x=0.15, y=0.08.

Fig 2(B) show the photoluminescence spectra of a violet and green emitting LEDs. As the amounts of $SrGa_2S_4$: Eu phosphor

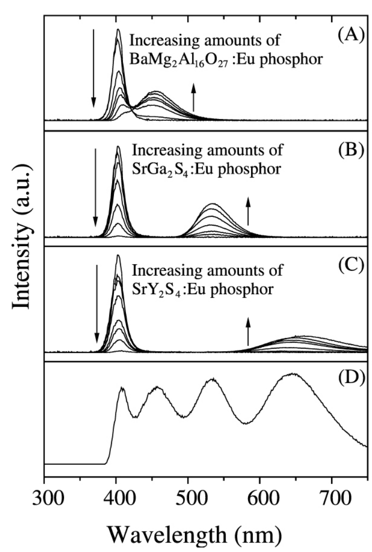

Fig 2. The photoluminescence spectra of (A) violet and blue emitting LEDs, (B) violet and green emitting LEDs, (C) violet and red emitting LEDs, and (D) four-band white LED, where $BaMg_2Al_{16}O_{27}$:Eu (blue), $SrGa_2S_4$:Eu (green), and/or SrY_2S_4:Eu (red) phosphors are coated to the violet LED.

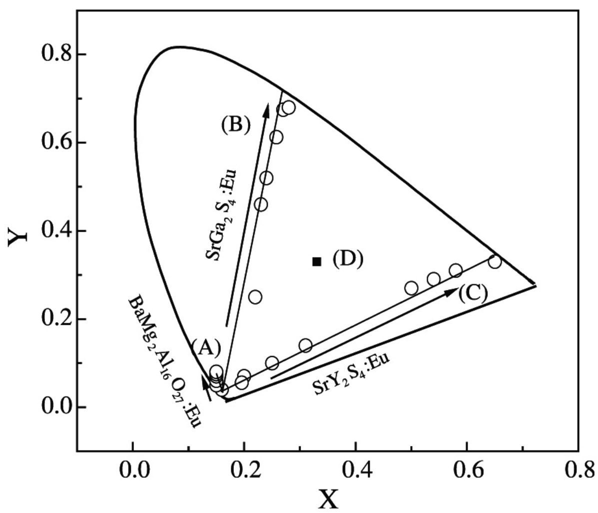

Fig 3. The CIE chromaticity coordinates of (A) violet and blue emitting LEDs, (B) violet and green emitting LEDs, (C) violet and red emitting LEDs, and (D) four-band white LED.

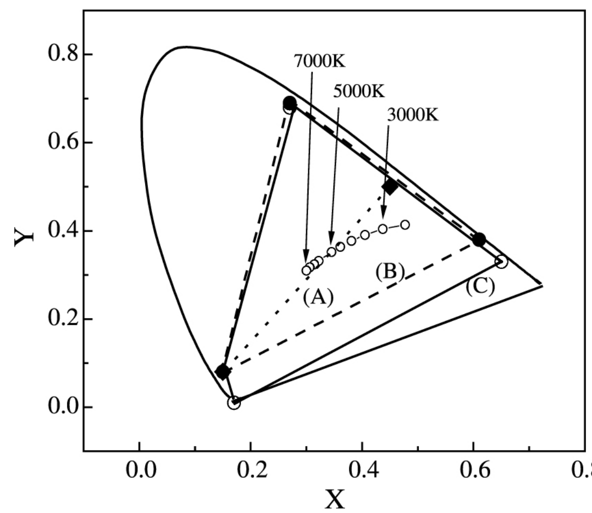

Fig 4. The CIE chromaticity coordinates of (A) blue LED with $Y_3Al_5O_{12}$:Ce phosphor for two-band white LED, (B) blue LED with $SrGa_2S_4$:Eu and ZnCdS:Ag,Cl phosphors for three-band white LED, (C) violet LED with $BaMg_2Al_{16}O_{27}$:Eu, SrGa2S4:Eu, and SrY_2S_4:Eu phosphors for four-band white LED. The Planckian locus and color temperatures are also shown.

is increased, the color shifts from violet to green. The chromaticity coordinates are close to the straight line interconnecting the points of the violet LED (x=0.17, y=0.01) and the $SrGa_2S_4$: Eu phosphor (x=0.27, y=0.68) as in Fig 3(B). Fig 2(C) also show the photoluminescence spectra of a violet and red emitting LEDs. As in Fig 3(C), the concentration of SrY_2S_4: Eu phosphor is increased, CIE chromaticity coordinates are converged to x=0.65, y=0.33. SrY_2S_4: Eu is an excellent red phosphor compared to ZnCdS: Ag,Cl (x=0.61, y=0.39) (7).

Fig 2(D) and 3(D) show the photoluminescence spectra of four-band white LED and CIE chromaticity coordinates of x=0.33 and y=0.33. The color temperature is about 5500K. The amounts of $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors are adjusted to generate the white color. Four distinct emission peaks are shown at 405, 450, 535, and 640 nm, which represent the violet, blue, green, and red, respectively. Therefore, we can obtain full color emitting LEDs by adjusting each amounts of $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and/or SrY_2S_4: Eu phosphors. Moreover, white light can be obtained around x=0.33 and y=0.33.

For commercial white LEDs (two-band white LEDs), different components of yttrium aluminum garnet (YAG), $(Y_{1-X}Gd_X)_3Al_{1-Y}Ga_Y)_5O_{12}$: Ce, must be synthesized to obtain white LEDs with different color temperatures (10). When the content of Gd is increased in $(Y_{1-X}Gd_X)_3Al_5O_{12}$: Ce phosphors, peak wavelength of emission shifts from 530 nm to a longer wavelength up to 570 nm. When white light of stronger red shade for lower color temperatures, it can be achieved by increasing the amount of Gd added 'in $(Y_{1-X}Gd_X)_3Al_5O_{12}$: Ce. Whereas the content of Ga is increased in $Y_3(Al_{1-Y}Ga_Y)_5O_{12}$: Ce phosphors, peak wavelength of emission shifts to a shorter wavelength. The white light of stronger blue shade with higher color temperatures can be achieved by increasing the amount of Ga added in $Y_3(Al_{1-Y}Ga_Y)_5O_{12}$: Ce phosphors. However, various color temperatures in four-band white LED can be easily made by simply mixing the different amounts of phosphors. The white light for lower and higher color temperatures can be obtained by coating higher amounts of red and green emitting phosphors onto a violet LED, respectively. This is the one of main advantages of the four-band white LED over the two-band white LED.

Fig 4 is a chromaticity diagram in which the two-band, three-band, and four-band LEDs are shown. The color of light emitted by a two-band LED in the chromaticity daigram is shown as the line by connecting two positions of a blue LED and $Y_3Al_5O_{12}$: Ce (yellow) phosphor (10). The color range of light emitted by a three-band LED is shown as the region inside each triangle which is drawn by connecting the positions of a blue LED, $SrGa_2S_4$: Eu (green), and ZnCdS: Ag,Cl (red) phosphors (7). The color range of a four-band LED is the region connecting the four positions of a violet LED, $BaMg_2Al_{16}O_{27}$: Eu (blue), $SrGa_2S_4$: Eu (green), and SrY_2S_4: Eu (red) phosphors. In Figure 4, the color range of four-band LED is the widest. This means that the four-band LED shows much better color purity in comparison with two-band and three-band LED. We are convinced that the four-band white LED has better color properties. Four-band white LED will be a good backlight source when it is used in full color display devices such as personal digital assistants.

Conclusions

A four-band white LED was fabricated by using a violet LED with $BaMg_2Al_{16}O_{27}$: Eu (blue), $SrGa_2S_4$: Eu (green), and SrY_2S_4: Eu (red) phosphors. Full color emitting LEDs and four-band white LEDs with different color temperatures can be obtained by simply adjusting each amounts of $BaMg_2Al_{16}O_{27}$: Eu, $SrGa_2S_4$: Eu, and SrY_2S_4: Eu phosphors. The four-band LED shows better color purity compared to two-band and three-band LED.

References

(1) Yam FK, Hassen Z (2005) Microelectr J **36**, 129
(2) Nakamura S (1997) Solid State Commun **102**, 237
(3) Schlotter P, Schmidt R, Schneider J (1997) Appl Plys A **64**, 417
(4) Shimizu Y, Sakano K, Noguchi Y, Moriguchi T (1999) US Patent 5, 998, 925
(5) Kim JS, Jeon PE, Choi JC, Park HL, Mho SI, Kim GC (2004) Appl Phys Lett **84**, 2931
(6) Sato Y, Takahashi N, Sato S (1996) Jpn J Appl Phys **35**, L838
(7) Huh YD, Shim JH, Kim Y, Do YR (2003) J Electrochem Soc **150**, H57
(8) Huh YD, Shim JH, Do YR. (2002) J Kor Chem Soc **46**, 164
(9) Do YR (2000) J Electrochem Soc **147**, 1597
(10) Huh YD, Cho YS, Do YR (2002) Bull Kor Chem Soc **23**, 1435

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