Indonesian Journal of Electrical Engineering and Informatics (IJEEI)
Vol. 12, No. 4, December 2024, pp. 1032~1039
ISSN: 2089-3272, DOI: 10.52549/ijeei.v12i4.4797

The Use of Green-Phosphor LuAG:Ce-Al_2O_3 for High-Luminosity Light Emitting Diode Packages

My Hanh Nguyen Thi[1], Nguyen Le Thai[2]
[1]Faculty of Mechanical Engineering, Industrial University of Ho Chi Minh City, Ho Chi Minh City, Vietnam
[2]Faculty of Engineering and Technology, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam

Article Info

Article history:

Received May 14, 2023
Revised Oct 6, 2023
Accepted Dec 1, 2023

Keywords:

Luminous flux
Light emitting diode
Green phosphor
Color quality

ABSTRACT

The LuAG:Ce-Al_2O_3 (LAGCA) green phosphor ceramic (GPC) is proposed for high-power white light emitting diodes (LEDs) in this paper. The luminescent properties of the GPC are examined with proper characterizing tools and under laser excitation. Then, LAGCA ceramic layer of 0.6 thickness is applied to fabricate the white LED. The results show LAGCA GPC is promising for high-power LED applications. The phosphor ceramic presents high thermostability and quantum efficacy and intense green emission peaking at nearly 550 nm. In the LED package, the amount of LAGCA in the composite layer is varied. The increasing dosage of LAGCA gives enhancement to the lumen output of the LED. However, the correlated color temperature stability and chromatic rendition declines. Thus, further improvements in LAGCA ceramic need to be carried out in the future works. Besdies, with the intense green emission, the LAGCA ceramics can be combined with red luminescent materials to increase the color performance of the LED lighting.

Corresponding Author:

My Hanh Nguyen Thi
Faculty of Mechanical Engineering, Industrial University of Ho Chi Minh City
No. 12 Nguyen Van Bao Street, Ho Chi Minh City, Vietnam
Email: nguyenthimyhanh@iuh.edu.vn

1. INTRODUCTION

Artificial lighting applications utilizing the solid-state illumination technology has quickly emesrsed in the lighting industry in recent decays and caught considerable attention for the development of new lighting generations. This type of light source presents many benefits, including being compact and friendly with nature, high light brightness and efficiency, long service life, and robustness [1-3]. Among commercial phosphor materials, the YAG:Ce^{3+} yellow phosphor is the most applied material. Yellow-emission YAG:Ce^{3+} phosphors have been applied extensively because they exhibit good blue-light absorption and lumen effcicacy [4, 5]. Traditionally, they are mixed with resisn composites, but the efficiency drops gradually after extended service time, especially in the high-power light LED in which the generated heat is significant. This indicating that the traditional YAG:Ce/resin composite is prone to aging and and yellowing problems. Many advancements have been made to improve the durability of the YAG:Ce^{3+} materials. For example, the YAG:Ce^{3+} phosphor-in-glass [6] and phosphor ceramics [7] were suggested as high thermal-conductivity materials. Notably, the phosphor ceramic presents more significant thermo-stability and conductitviy, higher homogeneity and robustness, and shorter preparation time. Hence, it can effectively high-power white light for LED applications under high density excitations like laser, ultraviolet, and infrared radiations.

The luminescent properties of the phosphor ceramic can be influences by many factors, such as the doping dosage of the ion activator, the secondary phase (SP), and the particle size [8-10]. The SPs often utilized to improve the tramission of the incident blue light, resulting in higher blue-light absorbing efficiency. Some of the most used SPs includes ZrO_2, $MgAl_2O_4$, and Al_2O_3. The Al_2O_3 SP has been doped into the YAG:Ce^{3+} phosphor ceramic and results in higher luminescence output for the ceramic. The Al_2O_3 SPs in the YAG:Ce^{3+} ceramic acts as effective scattering centers as they possess noticeable thermo-conductivity and well match with the YAG:Ce^{3+} ceramic configuration. Therefore, they efficienctly reduce the thermal quenching and increase the luminescent efficacy for the material [11, 12].

Besides the YAG:Ce^{3+} ceramic, the LuAG:Ce^{3+} ceramic is another potential material for the light converter materials as they present more significant thermo-conductivity and much lower thermo-quenching, which can stimulate their robustness for extended service periods. The ion actiovator Ce^{3+} in the LuAG material can induce the strong green emission. Therefore, on the basis of YAG:Ce^{3+}-Al_2O_3 phosphor ceramic development, the LuAG:Ce^{3+}-Al_2O_3 (LAGCA) green-emission phosphor ceramic (GPC) is suggested for the high-power white LED (HP-WLED) in this work. The prepared LAGCA ceramic exhibits high thermo-stability and strong green emission, and good blue-light absorption, suitable for HP-WLED applications. Nevertheless, the observed CCT stability and color redition efficiency of the WLED with LAGCA ceramics are not improved, indicating the needs of structure modification for the GPC in the future works [13, 14]. However, the strong green emission of the ceramic makes it suitable for the combination with red converter materials to improve the color rendering index (CRI) of the WLED devices.

2. METHOD

The ingredients and process of synthesizing the LAGCA ceramic are shown in Table 1. The solid-phase reaction and vacuum sintering are applied to synthesize the required ceramic. The doping concentration Ce^{3+} ion in the phosphor composite ceramic is fixed at 0.3 wt%. The amount of Al_2O_3 is determined at 40 wt%. The tetraethyl orthosilicate is added as sintering additive with an amount of 0.5 wt%. The ingerentdients are weighed stoichiometrically before starting the synthesis of LAGCA ceramic [15, 16]. The characterization methods of the fabricated LAGCA ceramics are demonstrated in Table 2. The WLED using the as-prepared LAGCA ceramic disks is depicted in Figure 1. The depicted WLED structure features nine disks separated into two symmetrical columns flanking a non-symmetrical column which each column containing an equal number of three disks. The LAGCA amounts used for examining WLED light properties varies from 5 wt% to 45 wt%.

Table 1. The ingredients and synthesizing process of the LAGCA ceramic

Ingredients	Synthesizing process
Lu_2O_3 Al_2O_3 CeO_2	1. Mixing the ingredients by ball-milling for 12 hours; ethanol is used as a dispersant. 2. Drying the mixture at 70 degrees Celsius for 2 hours (in air). 3. Sieving the mixture through a 200-mesh screen. 4. Calcinating the product at 600 degrees Celsius for 4 hours (in air). 5. 20-MPa pressing the obtained mixture into disks with 18-mm diameter. 6. Get the disks compacted using 250-MPa cold-isostatic-pressing process for 3 minutes. 7. Vacuum sintering the disks for 10 hours at 1750 degrees Celsius. 8. Annealing the disks for 10 hours at 1450 degrees Celsius. 9. Polishing the cemramic disks' surfaces to obtain the thickness of 0.6 mm for further examination.

Table 2. The characterization for the LAGCA ceramic

Characteristics	Determining methods
Morphology	Hitachi SU8220 field-emission scanning electron microscope, coupled with an energy-dispersive X-ray spectroscope
Total transmission	Varian Carry 5000 UV-Vis and NIR spectrophotometer
Internal quantum yeild	Spectroradiometer equipped with a blue laser diode (450 nm) and an integrating sphere
Emission and excitation spectra	Edinburgh FLS1000 fluorescence spectrofluorometer
Temperature-dependent luminescence spectra	Hitachi F-4600 fluorescence spectrophotometer
Lighting properties of WLED with LAGCA ceramic	HASS-2000 spectroradiometer equipped with an integrating sphere

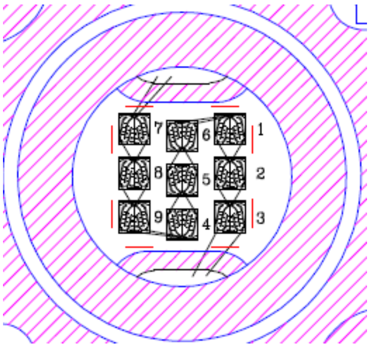

Figure 1. Structural depiction of WLED package used in the paper

3. RESULTS AND DISCUSSION

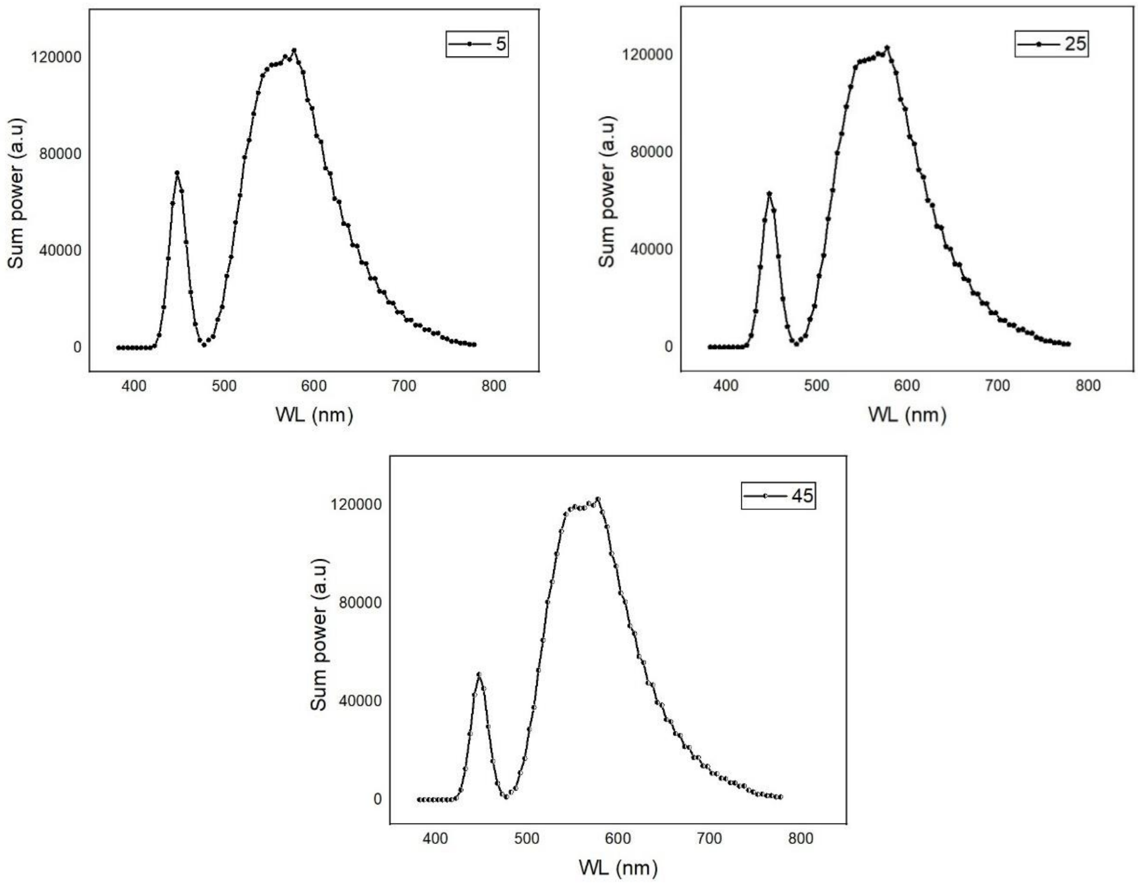

Figure 2. The total transmission power of the WLED in the presence of LAGCA phosphor ceramics

The total transmission power of the WLED in the presence of the LAGCA ceramic is shown Figure 2. The spectral bands in 450 nm and 535-600 nm are observed, which are probably induced by the addition of LAGCA ceramic. The ceramic is well excited under the 450-nm blue light excitation, giving the absorption peaks at around 450 nm due to the transition 4f-5d_1 of the ion dopant Ce^{3+}. Additionally, the intensity of spectra in the green region of 545-595 nm are more noticeable than the other, indicating that the blue-light conversion efficiency is enhanced, making it appropriate for high intensity green illumination [17, 18]. The enhancement in blue light conversion can be attributed to the enhanced scattering efficiency of emitted blue light in the WLED package when adding the GPC. Besdies, as the LAGCA ceramic is used in addition to the YAG:Ce^{3+} phosphor layer in the WLED model, the increase in LAGCA amount induces the reduction of YAG:Ce^{3+} dosage. The decrease of doping concentration of YAG:Ce^{3+} yellow phosphor with the higher LAGCA amount is illustrated in Figure 3. Such decrease of $YAG:Ce^{3+}$ yellow phosphor dosage also supports the scattering effectiveness of the incident blue light to serve the luminous improvement.

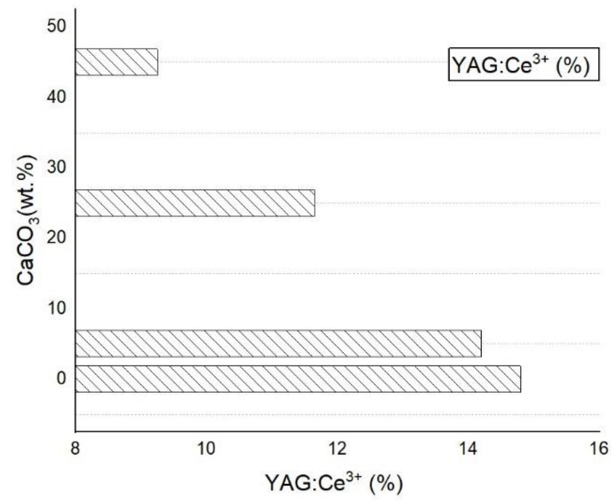

Figure 3. Doping concentration of $YAG:Ce^{3+}$ changes with higher LAGCA amounts

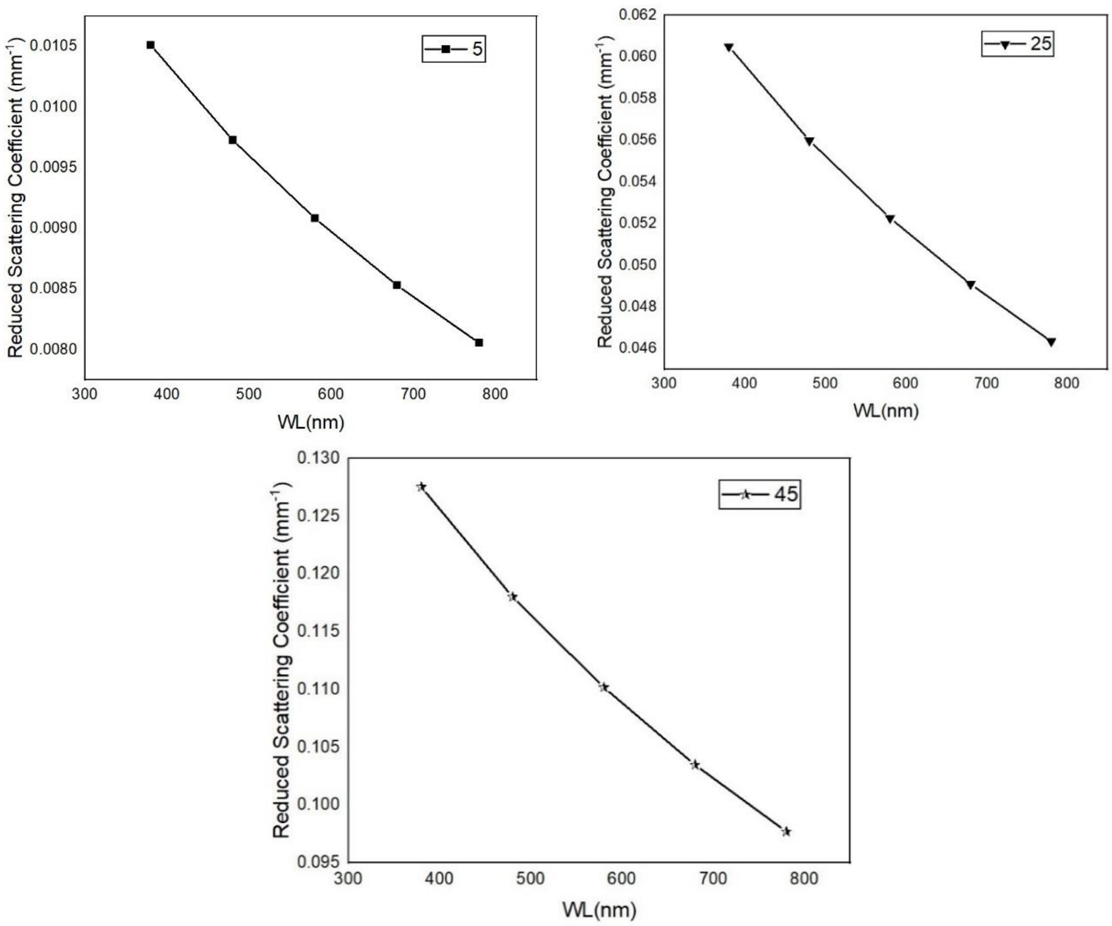

Figure 4. Reduce scattering coefficients of light in WLED in the presence of LAGCA phosphor ceramics

The scattering performance of the WLED increases as the concentration of LAGCA becomes larger, which is depicted in Figure 4. The ability to enhance the scattering performance of blue light could be ascribed to the structure of the LAGCA ceramic. In the GPC, there are some pores on the boundaries of the phosphor particles, which plays an important role as scattering centers to redirect the incident light path so that the absorption effectiveness can be improved. In addition, the addition of Al_2O_3 considerbly stimulate the multiple blue-light scattering as the propagation of light is supported. As a result, the blue-light conversion is more effective, leading to the higher quantum yield as well as higher emission intensity. Thus, the presence of LAGCA ceramic can promote the luminosity strength of the WLED package [19, 20].

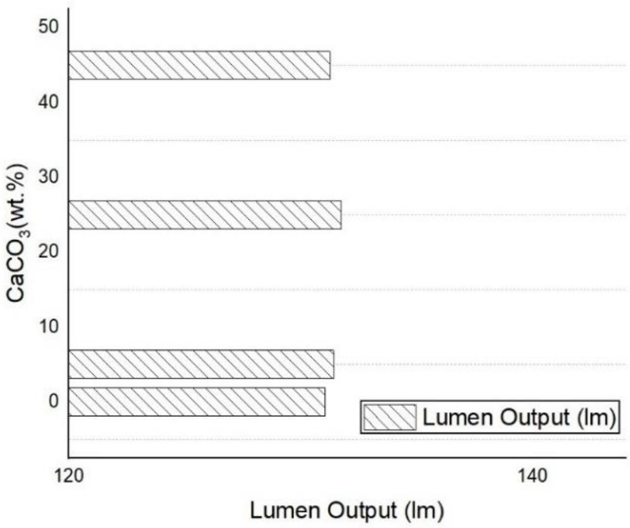

Figure 5. Lumen output changes with higher LAGCA amounts

Figure 5 illustrates the lumen output of the WLED with different amount of LAGCA. The intensity of lumen output increases as the amount of LAGCA increases from 0 wt% to 25 wt%. When the LAGCA amount continues increasing to 45 wt%, the luminosity starts to decline. It could be because of the reabsorption of the blue light as the LAGCA amount is significantly high. Besides, the increase in temperature during the operation of the WLED could contributes to induce the shorter-wavelength reabsorbing. Therefore, the emission peaks in spectra composition will move to the longer-wavelength region, resulting in the decrease in luminosity. However, the decrease of the WLED lumen output with high LAGCA amount is not too significant as the GPC has good thermostability.

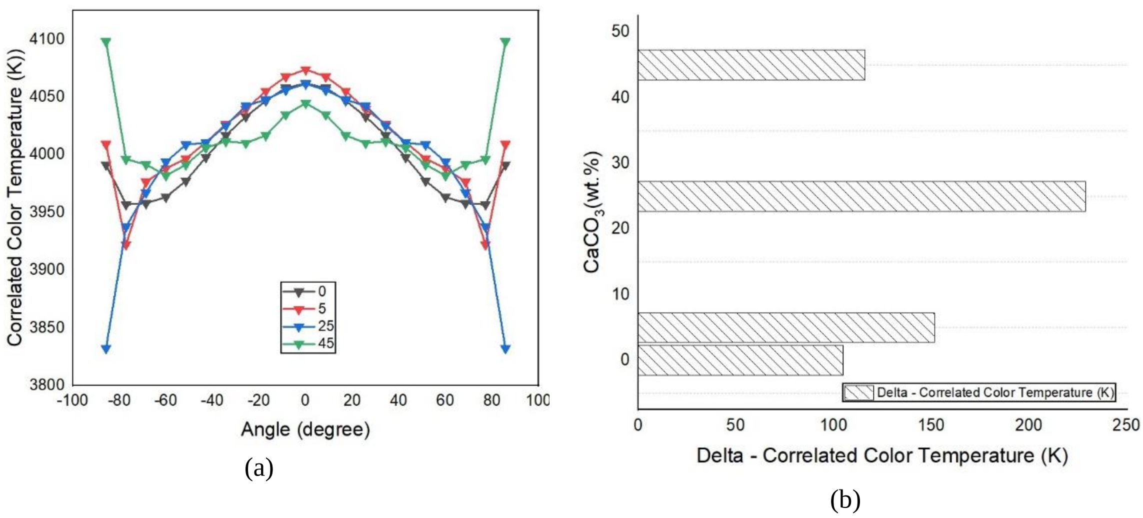

Figure 6. Color temperature (CT) properties of the WLED with different LAGCA amounts: (a) Angular CT and (b) CT deviation values

The color temperature (CT) properties of the WLED with different LAGCA amounts are shown in Figure 6, in which Figure 6a shows the angular CT values, and Figure 6b shows the deviation of CT values with increasing amount of LAGCA. The deviation of CT can support to determine the color uniformity of the WLED; the lower CT deviation indicates the higher color uniformity. It can be interpreted from the graphs that the CT increases as the LAGCA in introduced into the package (0-25 wt%). Increasing the LAGCA amounts above 25 wt% leads to the significant decrease in CT deviation. This can be the result of blue-light reflection on the ceramic surfaces. Though the CT at 45 wt% of LAGCA amount is still slightly higher than the one at 0 wt% LAGCA, it indicates the possibility in enhancing the CT stability and color uniformity with LAGCA ceramic.

The CRI and color quality scale (CQS) of the WLED light with different amounts of LAGCA are used to examine the performance of color rendition capability, which are shown in Figures 7 and 8, respectively. In both figures, it is easy to observe the decline in CRI and CQS [21, 22]. Such phenomena could be ascribed to the reflection of blue light and color imbalance in the spectra composition. As the LAGCA is introduced, the scattering is enhanced due to the higher absorption efficiency of the incident blue light, leading to more converted green lights. This also means the green light will become dominant, which is not favorable to the color rendition. The high color rendition requires broad light spectrum including at least three key colors: blue, green, and red to reproduce the best color fidelity of the illuminated objects. Thus, to acquire the higher color rendition performance, the red components should be supplemented by using luminescent phosphors or red LEDs [23-25].

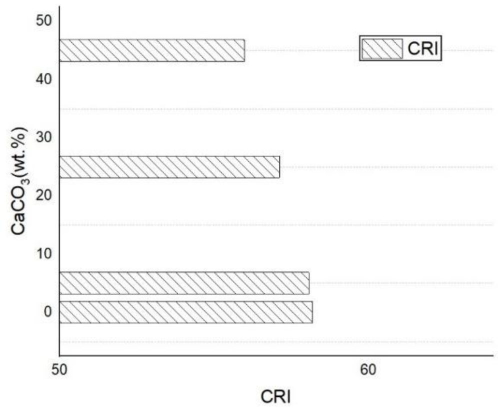

Figure 7. Color rendering index of the WLED with different LAGCA amounts

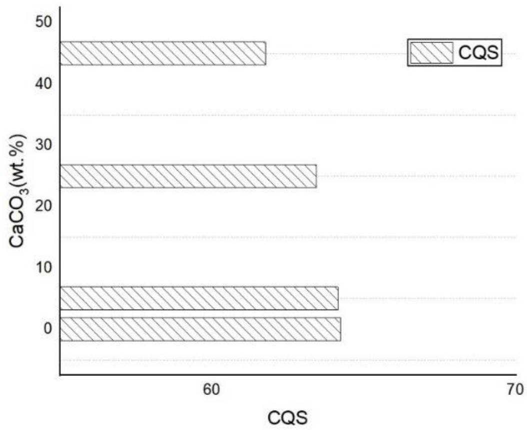

Figure 8. Color quality scale of the WLED with different LAGCA amounts

4. CONCLUSION

The LAGCA green-emission phosphor ceramic was synthesized through the solid-phase reaction route and the vacuum sintering. The obtained LAGCA ceramic has good thermostability and high emission of green color (545 nm), making it suitable for high-power WLEDs. The scattering of blue light in the WLED is significantly induced in the presence of the LAGCA ceramic owing to the efficient scattering centers and the secondary phase Al_2O_3 in the ceramic. The improvement of incident blue light leads to the higher blue-light absorbing and converting efficiencies, which stimulate the luminous intensity of the WLED. More than 25 wt% LAGCA can slightly reduce the luminosity because of the rise in blue-light reabsorption. The CT stability, CRI, and CQS of the WLED light shows the downward slopes in the presence of LAGCA owing to the reflection of blue light on the ceramic surfaces and the color imbalance in the total light spectrum. The LAGCA ceramic can be used with red-luminescent materials to increase the color quality of the high-power WLED lighting.

REFERENCES

[1] S. Biswas, J. Rohdin, A. Kavetskyi and M. Drahansky, "Grading Quality of Color Retinal Images to Assist Fundus Camera Operators," 2020 IEEE 33rd International Symposium on Computer-Based Medical Systems (CBMS), Rochester, MN, USA, 2020, pp. 77-82, doi: 10.1109/CBMS49503.2020.00022.

[2] K. Punnam Chandar, T. Satyasavitri, B. Narasimha and E. Hari Krishna, "Enhancement of color images by scaling Hirschman Optimal Transform coefficients," 2010 5th International Conference on Industrial and Information Systems, Mangalore, India, 2010, pp. 292-296, doi: 10.1109/ICIINFS.2010.5578692.

[3] D. Lee and K. N. Plataniotis, "Toward a No-Reference Image Quality Assessment Using Statistics of Perceptual Color Descriptors," in IEEE Transactions on Image Processing, vol. 25, no. 8, pp. 3875-3889, Aug. 2016, doi: 10.1109/TIP.2016.2579308.

[4] H. Prasetyo, A. R. Bagaskara and U. Salamah, "Quality Enhancement of Color-Embedded- Grayscale Image Using Convolutional Neural Network," 2021 International Conference on Converging Technology in Electrical and Information Engineering (ICCTEIE), Bandar Lampung, Indonesia, 2021, pp. 116-120, doi: 10.1109/ICCTEIE54047.2021.9650640.

[5] K. -T. Shih and H. H. Chen, "Exploiting Perceptual Anchoring for Color Image Enhancement," in IEEE Transactions on Multimedia, vol. 18, no. 2, pp. 300-310, Feb. 2016, doi: 10.1109/TMM.2015.2503918.

[6] H. Cui, G. Zhang, T. -Y. Wang, X. Li and J. Qi, "Combined Model Color-Correction Method Utilizing External Low-Frequency Reference Signals for Large-Scale Optical Satellite Image Mosaics," in IEEE Transactions on Geoscience and Remote Sensing, vol. 59, no. 6, pp. 4993-5007, June 2021, doi: 10.1109/TGRS.2020.3018591.

[7] M. Kim, K. S. Song and M. G. Kang, "No-Reference Contrast Measurement for Color Images Based on Visual Stimulus," in IEEE Access, vol. 6, pp. 23678-23687, 2018, doi: 10.1109/ACCESS.2018.2828830.

[8] C. Y. Yang and W. F. Wang, "Robust Color Image Watermarking Approach Based on Shape-Specific Points," 2014 Tenth International Conference on Intelligent Information Hiding and Multimedia Signal Processing, Kitakyushu, Japan, 2014, pp. 65-68, doi: 10.1109/IIH-MSP.2014.23.

[9] Q. Liu, H. Su, Z. Duanmu, W. Liu and Z. Wang, "Perceptual Quality Assessment of Colored 3D Point Clouds," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2022.3167151.

[10] L. Bao, K. Panetta and S. Agaian, "A no reference image quality measure using a distance doubling variance," 2015 IEEE International Conference on Technologies for Practical Robot Applications (TePRA), Woburn, MA, USA, 2015, pp. 1-6, doi: 10.1109/TePRA.2015.7219659.

[11] V. Gorbachev, E. Kaynarova, I. Metelev and E. Yakovleva, "On color-to-gray transformation for distributing color digital images," 2017 20th Conference of Open Innovations Association (FRUCT), St. Petersburg, Russia, 2017, pp. 77-82, doi: 10.23919/FRUCT.2017.8071295.

[12] A. Javaheri, C. Brites, F. Pereira and J. Ascenso, "A Point-to-Distribution Joint Geometry and Color Metric for Point Cloud Quality Assessment," 2021 IEEE 23rd International Workshop on Multimedia Signal Processing (MMSP), Tampere, Finland, 2021, pp. 1-6, doi: 10.1109/MMSP53017.2021.9733670.

[13] J. -H. Lee and M. -Y. Wu, "Reversible Data Hiding Scheme for Color Image Protection Based on Palette Color Replacement," 2008 3rd International Conference on Innovative Computing Information and Control, Dalian, China, 2008, pp. 24-24, doi: 10.1109/ICICIC.2008.471.

[14] Nai-Xiang Lian, V. Zagorodnov and Yap-Peng Tan, "Edge-preserving image denoising via optimal color space projection," in IEEE Transactions on Image Processing, vol. 15, no. 9, pp. 2575-2587, Sept. 2006, doi: 10.1109/TIP.2006.877409.

[15] S. I. Cho, S. -J. Kang and Y. H. Kim, "Image Quality-Aware Backlight Dimming With Color and Detail Enhancement Techniques," in Journal of Display Technology, vol. 9, no. 2, pp. 112-121, Feb. 2013, doi: 10.1109/JDT.2012.2236299.

[16] H. Liu, Y. Liao and T. Yang, "Computational verb color image interpolation," 2011 IEEE International Conference on Anti-Counterfeiting, Security and Identification, Xiamen, China, 2011, pp. 69-72, doi: 10.1109/ASID.2011.5967418.

[17] Shih-Chang Hsia, Ming-Huei Chen and Po-Shien Tsai, "VLSI implementation of low-power high-quality color interpolation processor for CCD camera," in IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 14, no. 4, pp. 361-369, April 2006, doi: 10.1109/TVLSI.2006.874367.

[18] Z. Jia, Q. Jin, M. K. Ng and X. -L. Zhao, "Non-Local Robust Quaternion Matrix Completion for Large-Scale Color Image and Video Inpainting," in IEEE Transactions on Image Processing, vol. 31, pp. 3868-3883, 2022, doi: 10.1109/TIP.2022.3176133.

[19] S. -J. Kang, S. Bae, J. -J. Yun and M. -Y. Lee, "Color Distortion-Aware Error Control for Backlight Dimming," in Journal of Display Technology, vol. 11, no. 1, pp. 79-85, Jan. 2015, doi: 10.1109/JDT.2014.2361513.

[20] R. Pan, W. Gao and J. Liu, "Color Clustering Analysis of Yarn-dyed Fabric in HSL Color Space," 2009 WRI World Congress on Software Engineering, Xiamen, China, 2009, pp. 273-278, doi: 10.1109/WCSE.2009.148.

[21] K. -S. Yang, P. -Y. Chen, C. -W. Chang and Y. -P. Chang, "A Low-Cost Color Interpolation Method for CCD Digital Still Camera," 2007 IEEE International Conference on Integrated Circuit Design and Technology, Austin, TX, USA, 2007, pp. 1-4, doi: 10.1109/ICICDT.2007.4299564.

[22] T. Li, T. Grenier and H. Benoit-Cattin, "Color space influence on mean shift filtering," 2011 18th IEEE International Conference on Image Processing, Brussels, Belgium, 2011, pp. 1469-1472, doi: 10.1109/ICIP.2011.6115720.

[23] S. -L. Chen and E. -D. Ma, "VLSI Implementation of an Adaptive Edge-Enhanced Color Interpolation Processor for Real-Time Video Applications," in IEEE Transactions on Circuits and Systems for Video Technology, vol. 24, no. 11, pp. 1982-1991, Nov. 2014, doi: 10.1109/TCSVT.2014.2317890.

[24] C. -L. Lim and R. Paramesran, "Blind image quality assessment for color images with additive Gaussian white noise using standard deviation," 2014 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS), Kuching, Malaysia, 2014, pp. 039-041, doi: 10.1109/ISPACS.2014.7024421.

[25] Kang Yao and Junyu Dong, "Removing shadows from a single real-world color image," 2009 16th IEEE International Conference on Image Processing (ICIP), Cairo, Egypt, 2009, pp. 3129-3132, doi: 10.1109/ICIP.2009.5414436.

BIOGRAPHIES OF AUTHORS

My Hanh Nguyen Thi received a Bachelor of Physics from An Giang University, VietNam, Master of Theoretical Physics And Mathematical Physics, Hanoi National University of Education, VietNam. Currently, she is a lecturer at the Faculty of Mechanical Engineering, Industrial University of Ho Chi Minh City, Viet Nam. Her research interests are theoretical physics and mathematical physics. She can be contacted at email: nguyenthimyhanh@iuh.edu.vn.

Nguyen Le Thai received his BS in Electronic engineering from Danang University of Science and Technology, Vietnam, in 2003, MS in Electronic Engineering from Posts and Telecommunications Institute of Technology, Ho Chi Minh, Vietnam, in 2011 and PhD degree of Mechatronics Engineering from Kunming University of Science and Technology, China, in 2016. He is a currently with the Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam. His research interests include the renewable energy, optimisation techniques, robust adaptive control and signal processing. He can be contacted at email: nlthai@ntt.edu.vn.