



Research Highlight

New red phosphors enable white LEDs to show both high luminous efficacy and color rendering index

Xiaoyong Huang ^{a,b}^a Institute for Advanced Study, Shenzhen University, Shenzhen 518060, China^b College of Physics and Optoelectronics, Taiyuan University of Technology, Taiyuan 030024, China

Today, energy saving and emission reduction are two big global issues. Power artificial lighting currently accounts for about 20% of the total global electricity consumption [1]. Solid-state lighting based on light-emitting diodes (LEDs) is bringing about a revolution in energy-efficient lighting, and the lighting industry is transformed into a rapidly growing business sector [2,3]. The solid-state lighting technology is basically based on phosphor-converted white LEDs (pc-LEDs), which are commonly fabricated by using the combination of InGaN blue-emitting LED chips and luminescent materials as color converters [4,5]. Luminescent materials play a critical role in fabricating high-performance LED devices, which is strongly linked to LED's luminous efficacy, stability, color rendering index (CRI), correlated color temperature (CCT) and operation lifetime [6–8]. Therefore, the discovery of more efficient desirable phosphor materials is essential.

For general lighting, the white pc-LEDs must offer warm white light showing low CCT (<3,500 K) together with both high luminous efficacy and CRI (>80). Although the current commercial white pc-LEDs based on InGaN blue chips and YAG:Ce³⁺ yellow phosphors can provide white light with high luminous efficacy, but their cool white emissions (CCT > 4,500 K and CRI < 75) limit them to the applications in the outdoor lighting, due to the lack of red component [9]. In order to realize superior white pc-LEDs with both high luminous efficacy and CRI, a red phosphor with a desirable emission spectrum should be developed and it must meet the following strict requirements [10–12]. First, the red phosphor possess narrow emission band with emission peak around 610–640 nm and full width at half maximum (FWHM) < 60 nm, because human eyes have very low sensitivity to the deep-red light. Second, the red phosphor also should have high quantum efficiency, low thermal quenching, reasonably short excited state lifetimes, strong absorption around 450 nm, and long-term physicochemical stability under ambient conditions. However, finding such a perfect red phosphor for white pc-LEDs has been challenging until now.

Recently, in a paper published in *Nature Communications*, Hoerder and co-workers [13] discovered a novel high-perfor-

mance red phosphor Sr[Li₂Al₂O₂N₂]:Eu²⁺ (abbreviated as SALON) meeting all requirements for a phosphor's optical properties, which enabled the white pc-LEDs to show both high luminous efficacy and CRI. Interestingly, the SALON phosphor exhibited a broadband absorption in the 370–600 nm region with peak around 450 nm, and under 460 nm excitation it gave rise to an intense narrowband red emission with peak at 614 nm and FWHM = 48 nm (Fig. 1). The emission properties of SALON were superior to the recently developed Sr[LiAl₃N₄]:Eu²⁺ narrowband red phosphor (emission peak at 654 nm and FWHM = 50 nm) [5]. Furthermore, the SALON possessed high quantum efficiency up to 80%, and it showed excellent thermal stability (the emission intensity at 420 K was about 96% of its initial value at 298 K). The fascinating luminescent properties of SALON red phosphor resulted from the high degree of condensation and a highly symmetrical Sr²⁺ coordination in its crystal structure. Finally, Hoerder and co-workers fabricated a warm-white prototype pc-LED by using green Lu₃(Al/Ga)₅O₁₂:Ce³⁺ and red SALON phosphors as color converters, and they found that the SALON-based pc-LED showed an increase of 16% in luminous efficacy compared to that of Sr[LiAl₃N₄]:Eu²⁺-based pc-LED, while retaining excellent high color rendition (CRI = 91).

The performance of SALON can be further improved by optimizing the synthesis conditions or Eu²⁺ doping concentrations [14]. Moreover, the long-term stability of SALON is needed to test before their practical applications [15], while coating an inert layer might protect SALON against the degradation and thus enhance its stability [16,17]. Furthermore, the optical properties of SALON may be tuned by using partial substitution of Ba or Ca for Sr [12,18].

In summary, the big breakthrough in finding a high-performance narrowband red phosphor made by Hoerder and co-workers is a piece of exciting news to the community of LED phosphors. Such phosphors have great potential for industrial applications in high-power white pc-LEDs and then brighten the world with less energy consumption.

Conflict of interest

The author declare that he has no conflict of interest.

E-mail address: huangxy04@126.com

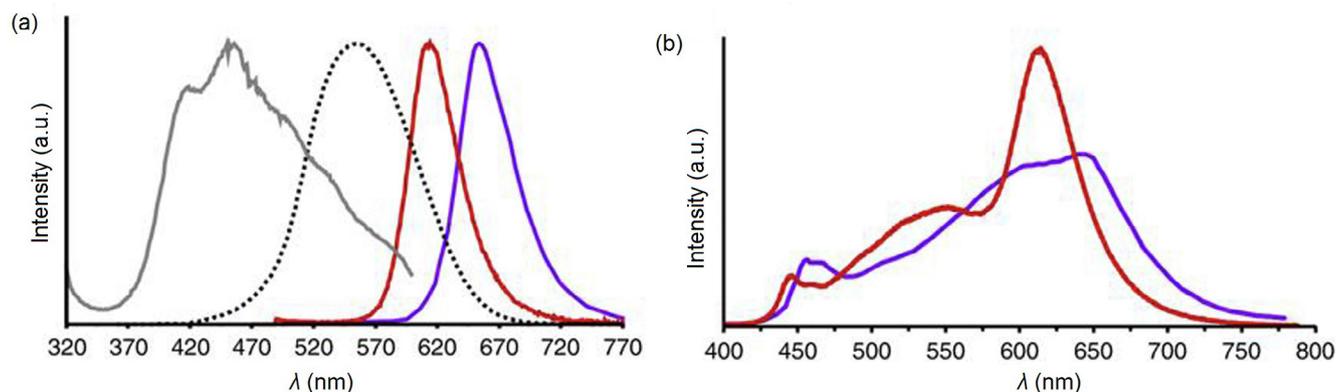


Fig. 1. Excitation and emission spectra of SALON (a) and warm-white pc-LED fabricated by using the SALON phosphor as red component (b). Adapted with permission from Ref. [13]. Copyright (2019) Springer Nature.

References

- [1] Pimputkar S, Speck JS, DenBaars SP, et al. Prospects for LED lighting. *Nat Photonics* 2009;3:180–2.
- [2] Pust P, Schmidt PJ, Schnick W. A revolution in lighting. *Nat Mater* 2015;14:454–8.
- [3] Cho J, Park JH, Kim JK, et al. White light-emitting diodes: history, progress, and future. *Laser Photon Rev* 2017;11:1600147.
- [4] Huang X. Solid-state lighting: red phosphor converts white LEDs. *Nat Photonics* 2014;8:748–9.
- [5] Pust P, Weiler V, Hecht C, et al. Narrow-band red-emitting $\text{Sr}[\text{LiAl}_3\text{N}_4]:\text{Eu}^{2+}$ as a next-generation LED-phosphor material. *Nat Mater* 2014;13:891–6.
- [6] Xia Z, Xu Z, Chen M, et al. Recent developments in the new inorganic solid-state LED phosphors. *Dalton Trans* 2016;45:11214–32.
- [7] Lin CC, Liu RS. Advances in phosphors for light-emitting diodes. *J Phys Chem Lett* 2011;2:1268–77.
- [8] George NC, Denault KA, Seshadri R. Phosphors for solid-state white lighting. *Annu Rev Mater Res* 2013;43:481–501.
- [9] Sato Y, Kato H, Kobayashi M, et al. Tailoring of deep-red luminescence in $\text{Ca}_2\text{SiO}_4:\text{Eu}^{2+}$. *Angew Chem Int Ed* 2014;53:7756–9.
- [10] Zhu H, Lin CC, Luo W, et al. Highly efficient non-rare-earth red emitting phosphor for warm white light-emitting diodes. *Nat Commun* 2014;5:4312.
- [11] Smet PF, Parmentier AB, Poelman D. Selecting conversion phosphors for white light-emitting diodes. *J Electrochem Soc* 2011;158:R37–54.
- [12] Osborne RA, Cherepy NJ, Åberg D, et al. $\text{Ba}_{1-x}\text{Sr}_x\text{Mg}_3\text{SiN}_4:\text{Eu}$ narrowband red phosphor. *Opt Mater* 2018;84:130–6.
- [13] Hoerder GJ, Seibald M, Baumann D, et al. $\text{Sr}[\text{Li}_2\text{Al}_2\text{O}_2\text{N}_2]:\text{Eu}^{2+}$ —a high performance red phosphor to brighten the future. *Nat Commun* 2019;10:1824.
- [14] Cui D, Xiang Q, Song Z, et al. The synthesis of narrow-band red-emitting $\text{SrLiAl}_3\text{N}_4:\text{Eu}^{2+}$ phosphor and improvement of its luminescence properties. *J Mater Chem C* 2016;4:7332–8.
- [15] Li W, Song Z, Cui D, et al. Moisture-induced degradation of the narrow-band red-emitting $\text{SrLiAl}_3\text{N}_4:\text{Eu}^{2+}$ phosphor. *J Rare Earths* 2018;36:341–5.
- [16] Nguyen HD, Lin CC, Liu RS. Waterproof alkyl phosphate coated fluoride phosphors for optoelectronic materials. *Angew Chem Int Ed* 2015;54:10862–6.
- [17] Guo C, Chu B, Wu M, et al. Oxide coating for alkaline earth sulfide based phosphor. *J Lumin* 2003;105:121–6.
- [18] Yao F, Wang L, Lv Y, et al. Composition-dependent thermal degradation of red-emitting $(\text{Ca}_{1-x}\text{Sr}_x)\text{AlSiN}_3:\text{Eu}^{2+}$ phosphors for high color rendering white LEDs. *J Mater Chem C* 2018;6:890–8.



Xiaoyong Huang obtained his Ph.D. degree from South China University of Technology in 2011. Afterwards, he worked as postdoctoral researcher at the National University of Singapore. His current research mainly focuses on the design, synthesis and characterization of functional materials towards applications in photonic and optoelectronic devices, sensors, and photocatalysis.