Critical review on lanthanide activated LED phosphors

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Abstract. Broad range of phosphors has been utilized for LEDs in past few years, subsequently, encourages the phosphor-converted LEDs (pc-LEDs). Proposed article gives an idea about the different color tunable phosphors used in solid state lighting. Different properties of different color emitting phosphors have been done with the mixing of rare earths in the host lattice of luminescent centered materials which shows color emission in the visible range. There is a concise approach toward the different characteristics and records related with the color quality and execution of pc-LEDs. So this article mainly deals with role lanthanides in LED phosphors and their characteristics in the field of luminescence. Keywords: rare earth ions, LEDs, phosphors, luminescence, color tunable.

1. Introduction

Different kind of luminescent materials have paid attention in recent years in the research field including in solar cells, light emitting diodes (LEDs) and bio-imaging having outstanding luminescence efficiency[1–3]. Among all the different luminescent materials, oxide semiconducting materials are beneficial due to their properties like non-toxicity and lower cost. In recent times, ZnTiO3 has paid attention owing to their wide bandgap, exceptional chemical and physical properties, which make it appropriate for proficient rare earth activated luminescent materials for LED applications [4,5]. Trivalent europium (Eu3+) ions are the great example which competently converts ultraviolet photons to in the photons of visible range. On activating host lattice by Eu3+ ions, it is dope in non-centrosymmetric sites of host lattice and emits strong red color due to 5D0→7F2 transition transition[8].

As per the researchers, the 5D0→7F1 transition occurs due to magnetic dipole transition it depends on the site symmetry occurred in the host lattice due to doping of trivalent europium ions[9]. It is eminent that enhancements of the luminous efficiency of the phosphor materials are improved with enhance the concentration of the trivalent rare earths doped in the host lattice. But luminescence intensity get diminished on enhancing concentration of rare earth is referred as concentration quenching effect[10–12]. Co-doping of rare earth ions has been used for the improvement of luminous efficiency which act as an activator or charge compensator.

Host lattice activated by Sm3+ ions produce extreme intensity owing to energy transfer from Sm3+ ions to host lattice. Sm3+ activated host lattice shows solid orange-red color in the emission spectrum because of 4G5/2→4H3/2 (J = 5/2, 7/2, 9/2, 11/2 transitions[13]. This intensity of emission spectrum gets enhanced
by doping of charge compensator like Li$^+$ ion. Accordingly, doped material PL intensity increments by methods for improvement of the nearby balance around the activators by Li$^+$ ions.

2. Role of lanthanides in LED phosphors
Lanthanides activators are most important rare earths used in the preparation of phosphors for solid state lighting. All fifteen elements under the lanthanide series that extend from lanthanum (La) to lutetium (Lu). By no means, the wide ranges of various components of the lanthanide series are portrayed by partly filled 4f orbital. The 4f orbitals are set into the ions and it protected by completely filled 5s to 5p orbitals from its environment, therefore the host material shows its impact on the transitions carried out in the 4f orbital. The majority of the lanthanides (in their trivalent state) show sharp line spectra inferable from these transitions. Due to these transitions, most of the lanthanide ions show sharp emission spectra. Be that as it may, these transitions are spectroscopically prohibited and henceforth, show up with feeble intensity more often than not. The crystal structure symmetry id directly influenced on the selection rules for the transition controlling. There are two types of transitions that are magnetic dipole and electric dipole or both transitions combined together. Magnetic dipole transition does not affect the site-symmetry. Consequently, the crystal site symmetry makes an impact on the electric dipole transition[14,15].

3. Color tunability
To meet the necessities of present-day lighting innovation, endeavors are being made to obtain materials able to color tuning so as to might likely build up the luminous efficiency and color extent of pc-LEDs. Photochromic phosphor makes an immense revolution in the change in lighting generations. An array of all these examination work can frame a free investigation that will smirch the current concepts known to us and give further comprehension about the approach and veritable systems associated with these new kinds of radiant materials. Despite the fact that our survey isn't explicitly committed on the photochromic phosphors, we emphatically accept that this subject will likewise be incorporated as an essential piece of this audit. There are bounties of photochromic phosphors revealed, however we will immediately restrict our debate just on those pertinent for pc-LEDs[16,17].

Excitation spectrum and PL emission spectra of BaSiF$_6$:Ce$^{3+}$-Eu$^{2+}$ are displayed in figure 1 and 2 respectively. Figure 3 shows the CIE color chromaticity diagram of BaSiF$_6$:Ce$^{3+}$-Eu$^{2+}$ co-doped phosphors. There are various conceivable outcomes to accomplish color tuning with Ce$^{3+}$ alongside Eu$^{2+}$, Tb$^{3+}$, Eu$^{3+}$, and so forth. In any case, the majority of their excitation spectra don't cover with the emission spectra of InGaN or GaN chips. In many cases Ce-activated luminescent phosphors are not applicable for pc-LED applications. But there are few samples which are exception for this like Y$_2$SiO$_5$:Ce$^{3+}$, Tb$^{3+}$, Eu$^{3+}$ which is useful in the LED phosphors. The triple doping of Ce$^{3+}$, Tb$^{3+}$ and Eu$^{3+}$ makes an efficient phosphor for color tuning from blue → white → orange/red[18,19].
Figure 1. PL excitation spectrum of BaSiF$_6$:Ce$^{3+}$-Eu$^{2+}$ codoped phosphor (Reprinted with the permission from ref. [20] ©Elsevier publications)

Figure 2. PL emission spectra of Ce$^{3+}$-Eu$^{2+}$ codoped phosphor (Reprinted with the permission from ref. [20] ©Elsevier publications)
4. Characteristics of LED phosphors

The superiority and the amount of yield got from light source choose the legitimacy of the examination on that specific light source. Despite the fact that allowing for any wellspring of light for enlightenment reason, it is crucial to comprehend the manner in which it is observed by person eyes. Various quantitative measurements have been fashioned to portray and enhance the lighting configurations regarding apparent excellence. The CIE (Commission Internationale de l'Eclairage) is as of now the main globally acknowledged organization giving counsel to LED estimations.

Measurable investigations of a few person issues were utilized to normalize the discrimination reactions to light improvements. The person eyelash, which is the light delicate piece of human eyeball, encloses two sorts of cells, in particular, rod cells and cone cells. Rod cells of the human eye are more sensitive as compare to the cone cells over the whole visible spectrum. The cone cells are ordered keen on three sorts relying upon their affectability to blue, green and red-light spectrum. Photometric units are needed for describe the light and color sense by person eye. Four types of radiometric measurements were available like irradiance, radiant intensity, flux and brilliance. Absolute force discharged per unit time by light is referred as radiation flux and its unit is watt (W).

4.1 Color Rendering Index (CRI)

The capacity to provide genuine impression of colors that is being enlightened by light source is known to be color rendering. Proportion of light source to uncover this capacity is communicated regarding Color rendering Index (CRI). Open air depicts the articles impeccably as it has a CRI of 100 %. This implies that superior the CRI displayed by a light source, which a lot nearer will be the light discharged by the source so as to of sunlight. Other than brilliance and viability of the solid-state lighting luminaries, it is regularly vital that it ought to have a high color rendering index. Rare earth activated phosphors utilized in solid
state lighting add to the general assembling costs. Henceforth, makers frequently settle on inferior eminence phosphors to bring down the expense of the luminaire. However, this effectly affects the white light delivered from the solid-state lighting as it seems to create distinctively appearing to be white colors at various marks. This is clear indication of inferior excellence. Keeping up same shade immaculateness is a difficult undertaking for LED producers as Color rendering is a basic highlight be thought of. For good solid state lighting, top notch phosphor is needed for accomplishing high CRI[18,19].

4.2 CIE chromaticity coordinates
The Commission Internationale de l'Eclairage (CIE) was organized in 1913 as a worldwide independent organization to set all inclusive principles relating to light and trade of thoughts identified with the study of light, shade, visualization and lighting. Despite the fact that these forms were presented by means of a remedy in the nonconsistency observed in 1931 diagram, they were not totally liberated from distortion and thus, neglected to outperform the ubiquity of the first form. The 1931 CIE graph utilizes tristimulus esteem X, Y, Z to depict the arrangement of colors on the color space. [21,22].

4.3 Color correlated temperature (CCT)
Light source is, generally, indicated regarding color temperature intended for portraying the color manifestation of light resource through associating it by means of temperature of a supreme blackbody radiator. CCT is expressed in terms of Kelvin (K). Notwithstanding, this phrase is genuinely restricted in the direction of just those light sources to facilitate work with thermal radiation. However, there are a few different wellsprings of light that emanate light by radiance as opposed to incandescence. Notwithstanding, the real temperatures related with these requisites appear selected somewhat befuddling. Temperatures in the range from 2500 to 3500 K are warm color light while cool colors emits at temperature more than 5000 K[23].

5 Concluding remark
The quick progression in LED innovation has cleared route to various developments. Presently, solid state lightings are not simply restricted to lighting requirements. Their huge applications in innumerable areas are increasing tremendous profound respect. The changing necessities prompted various adjustments in the LED arrangement and this have empowered LEDs to push ventures forward from the well-established semiconductor material science. One of the significant worries in crude semiconducting solid-state lighting was the trouble to acquire a color frequency other than the essential colors’ by a solid chip. This might have been understood if RGB chips were joined admirably to create a particular color of significance. Be that as it may, every one of these chips demonstrates distinctive corruption with time and henceforth, the mix will neglect to work out on a long drag. Consequently, phosphors arose out to be a choice in this emergency. Rather than three costly semiconductor chips, the new setup requisite just a solitary chip that can siphon the phosphor.

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