# STUDY OF TUNABLE MULTICOLOR EMISSION BY RARE EARTH DOPED $SR_2CEO_4$ FOR PHOSPHOR-CONVERTED WHITE LIGHT

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## ABSTRACT

**$Sr_2CeO_4$ is well- known host lattice for efficient multicolor emitting luminescence material with different activators, keeping this view we doped rare earth ions $Dy^{3+}$, $Gd^3$, $Eu^{3+}$ in $Sr_2CeO_4$ material and prepared all these samples by the easy combustion method. Prepared sample shows flexible intensity of multicolor optics region for phosphor-converted white light application. $Sr_2CeO_4$ shows the interesting optical properties in powder form due to the presence of two phases and doubly ionized oxygen vacancies. The crystal structure was ascertained through X-ray diffraction analysis. Prepared $Sr_2CeO_4$:$Dy^{3+}$, $Sr_2CeO_4$:$Gd^{3+}$ and $Sr_2CeO_4$:$Eu^{3+}$ samples are examined by emission and excitation spectra for solid state lighting applications (SSL) under commercial available NUV exciting source. SEM images and XRD patter of prepared sample are taken to study surface morphology which shows particles of irregular size and average size in nanometer range. Prepared luminescence materials can also be used to improvement of efficiency of solar cells, field emission display panels and light emitting diodes under commercially available NUV (350-420 nm) and blue (430-470 nm) light .**

**Keywords: $Dy^{3+}$, $Gd^{3+}$, $Eu^{3+}$, $Sr_2CeO_4$, Phosphor-converted white light.**

## 1. INTRODUCTION

$Sr_2CeO_4$ gives excellent high luminescence efficiency, flexible emission colors with different activators thus used to improvement of efficiency of solar cells, field emission display panels and light emitting diodes, when excited by the UV light [1.2]. Near-UV LEDs when coupled with white light emitting phosphor materials which emit red, green and blue light in a specific ratio are very economical and interesting for intense WLEDs [3,4]. Today light emitting materials which efficiently absorbed NUV (350-420 nm) and blue (430-470 nm) light are easily available with efficiency of 2 Watt/$m^2$ to 8 Watt/$m^2$ [5,6]. Inorganic $Sr_2CeO_4$ is one of the smart blue light emitting luminescence materials and also a very good ceramic materials [7], used as a scintillations, which convert high energy ionizing photons, and used in medicine, oil logging environmental monitoring and particle physics [8]. $Sr_2CeO_4$ nanophosphors with non rare earth elements (Ca, Mg, Ba, Zn) doping also produce tunable photoluminescence [9, 10]. Due to the presence of $SrCeO_3$ and $SrCO_3$ phases, which have an impact on the deconvoluted bands in the emission spectra, $Sr_2CeO_4$ exhibits fascinating optical features in powder form. The band gap of $Sr_2CeO_4$ material is approximately 3.4 eV, thus it's a good candidate for use as a scintillation or in the improvement of efficiency of solar cells, when excited in the UV and visible region. The (PL) emission peaks of both $Eu^{3+}$ and $Eu^{2+}$ activated $Sr_2CeO_4$ phosphors at 467 (blue), 537 (green) and 616 nm (red) generate white light under 260, 280 and 350 nm[9,10] but intensity of red light is not sufficient with deficiency yellow region light. Santosh K. Gupta et al;, prepared Bluish white emitting $Sr_2CeO_4$ and red emitting $Sr_2CeO_4$:$Eu^{3+}$ nanoparticles by polymeric precursor route [11,12], which consist of infinite edge-shearing $CeO_6$ octahedral chains separated by Sr atoms, it is also found that emission radiation of $Sr_2CeO_4$:$Eu^{3+}$ nanoparticles

depends on temperatures thus it can be use for nanothermometry technology[13]. The broad blue emission band of $Sr_2CeO_4$ makes it suitable for the doping of rare earth ions so that it emit tunable different radiation in visible region, that can use to obtain day sun light emission for solid state lighting. Rare earth ions doped $Sr_2CeO_4$ nano phosphor shows good luminescence intensity and good crystaline structure at high calcination temperature [14-17].

## 2. EXPERIMENT

We synthesis rare earth doped $Sr_2CeO_4$ phosphor by combustion method for that we first dissolve $Sr(NO3)_2$ (99.99%) and $Ce(NO_3)_3$ (99.99%) in dilute $HNO_3$ (AR) in separate beakers. Then $Gd_2O_3$(99.99%), $Dy_2O_3$(99.99%), $Eu_2O_3$ (99.99%) are separately dissolved in dilute $HNO_3$ solutions to form nitrate solutions in proper stoichiometric ratio. Then to form $Sr_2CeO_4:Dy^{3+}$ the nitrate solutions of $Sr(NO3)_2$, $Ce(NO_3)_3$ and $Dy_2O_3$ are pour in a beaker and stirred well to form uniform mixture. Now urea is used as reducing agent keeping urea to nitrate molar ratio as 2:1. Then mixture was set aside in a crucible and heated at 500 to $550^0$ C in a furnace for 8-15 minute then it translate to white powder, which after grinded a consistent powder was achieve. lastly, powder was kept in furnace at $800^0$C for 2 hour to eradicate other impurities. Likewise, other samples are created and used for characterization.

## 3. RESULTS & DISCUSSION:

### 3.1 POWDER X-RAY DIFFRACTION

To obtain phase purity and crystallite structure we take X-ray diffraction of $Sr_2CeO_4$ phosphor which is shown in figure 1. The XRD peaks positions are well matched with JCPDS card No.22-1422 [18], which belongs to triclinic crystal structure. Diffraction patterns shown in figure 1 were obtain using Cu $K_\alpha$ wavelength ($\lambda$= 1.5404 A°), at 40 kV and 30 mA applied to x-ray tube. and glancing angle 2 theta varies from 10° to 75° keeping scan step time = 4.8450 second. The average size of the powder particles were calculated using calculated from X-ray peak broadening of the diffraction using Scherer's formula.

$$d = \frac{0.9\lambda}{\beta \cos\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, $\beta$ denote the full width at half maximum (FWHM) of XRD peaks, $\lambda$ is wavelength of X- ray and $\theta$ denote angle of diffraction. The average particle size of rare earth doped $Sr_2CeO_4:Eu^{3+}$ is found to be 174 nm.

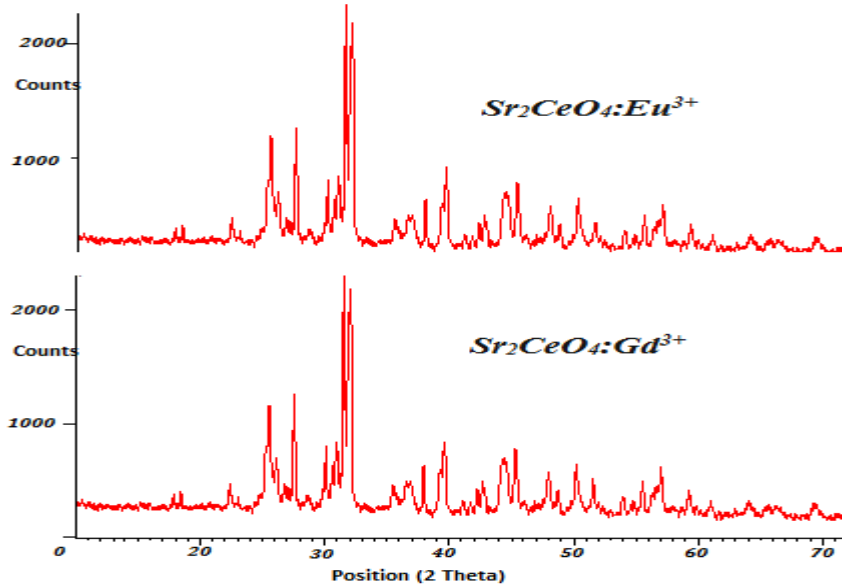


***Fig. 1:*** **powder X-ray diffraction *pattern of $Sr_2CeO_4:Eu^{3+}$ and $Sr_2CeO_4:Gd^{3+}$*.**

### 3.2 SEM RESULT

SEM images of rare earth doped $Sr_2CeO_4$ phosphor prepared by combustion method are shown in figure 2. SEM images of figure 2(a) $Sr_2CeO_4:Eu^{3+}$ = 1 mol% before sintering shows more agglomeration than figure 2(b), these

agglomerated particles have irregular surfaces and non uniform morphology. Figure2(c) $Sr_2CeO_4:Gd^{3+}$ = 1 mol% shows the irregular particles and average size of 705 nm. Figure 2(d) shows the surface morphology of $Sr_2CeO_4:Dy^{3+}$ = 1 mol%.

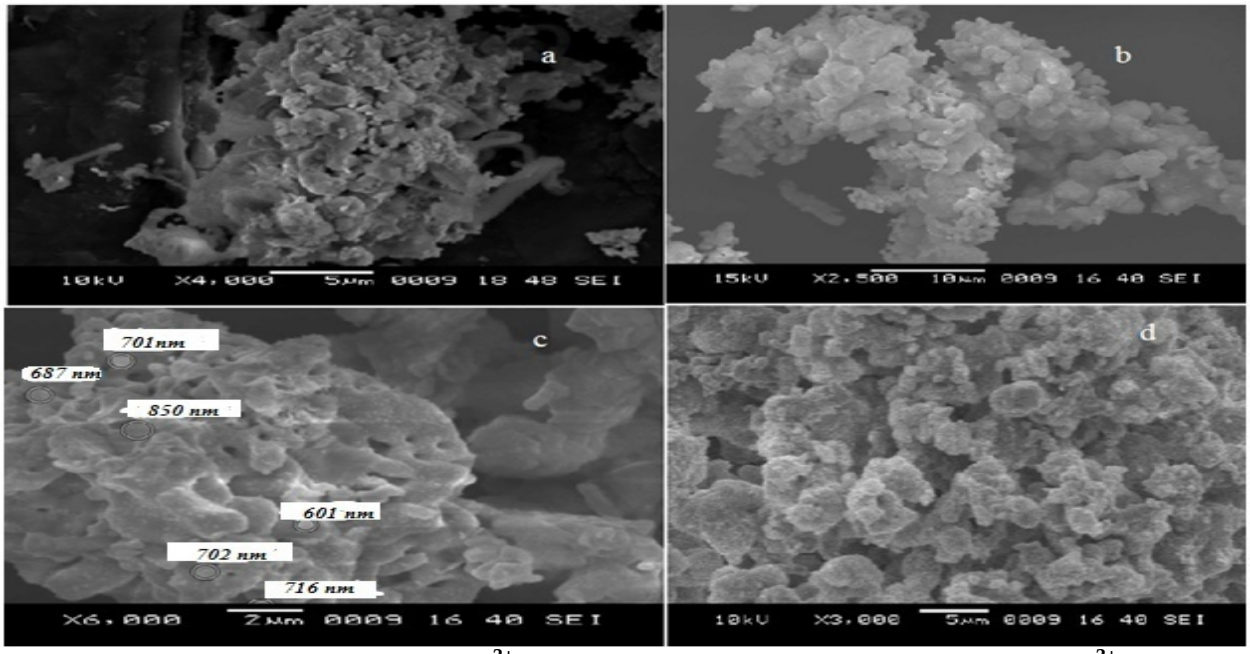


***Fig. 2 SEM images of (a) $Sr_2CeO_4:Eu^{3+}$ = 1 mol% before sintering (b) $Sr_2CeO_4:Eu^{3+}$ = 1 mol% after sintering at 800 °C (c) $Sr_2CeO_4:Gd^{3+}$ = 1 mol% and (d) $Sr_2CeO_4:Dy^{3+}$ = 1 mol%.***

### 3.3 PHOTOLUMINESCENCE RESULTS

The excitation spectra of prepared rare earths ($Eu^{3+}$, $Dy^{3+}$, $Gd^{3+}$) ions doped $Sr_2CeO_4$ shows extending from 220 nm to 380 nm in the blue–green region with the maximum (FWHM~86) with peak at about 280 exciting at 570 nm visible radiations (Fig.3). The emission spectra recorded on exciting at 254, 260, 280 as well as 350 nm show a broad band with the maximum (FWHM~146) with extended emission into longer wavelengths.

The leading peak 280 nm and another peak at around 340 nm may be allocate to two availability of two sides of $Ce^{4+}$ ions in $Sr_2CeO_4$. There are two different $Ce^{4+}$-$O^{2-}$ bond lengths in the lattice and hence two unlike charge transfer transitions take place. The emission spectra of rare earth doped $Sr_2CeO_4$ beneath viable available NUV light source is shown in figure 4, where we see that $Dy^{3+}$ doped $Sr_2CeO_4$ gives high strength peak at 573 nm and a wide peak at about 481 nm and $Gd^{3+}$ doped $Sr_2CeO_4$ gives high intensity peak at 527 nm and a wide peak at about 480 nm whereas D. L. Monika, et al; prepared $Gd^{3+}$ doped $Sr_2CeO_4$ by Solid State Diffusion method which gives a broad band with peak at 470 nm[17] . $Eu^{3+}$ doped $Sr_2CeO_4$ gives as many peaks at 468, 492, 512, 538,557, 586, 596, 615 nm. From earlier research paper study we see that $Sr_2CeO_4$: $Sm^{3+}$ shows emission peaks at 387,474,556, 611, 653 nm [13, 15]. The broad band emission originates from $Sr_2CeO_4$ host itself and $Eu^{3+}$, $Sm^{3+}$ co doped $Sr_2CeO_4$ shows peaks at 387,467,474, 491, 511, 538, 556, 611,586, 616, 653 nm. Thus emission lines in the blue, green, and red region coexist. Thus $Sr_2CeO_4$ can be a good phosphor material for lamps and display devices [19-25].

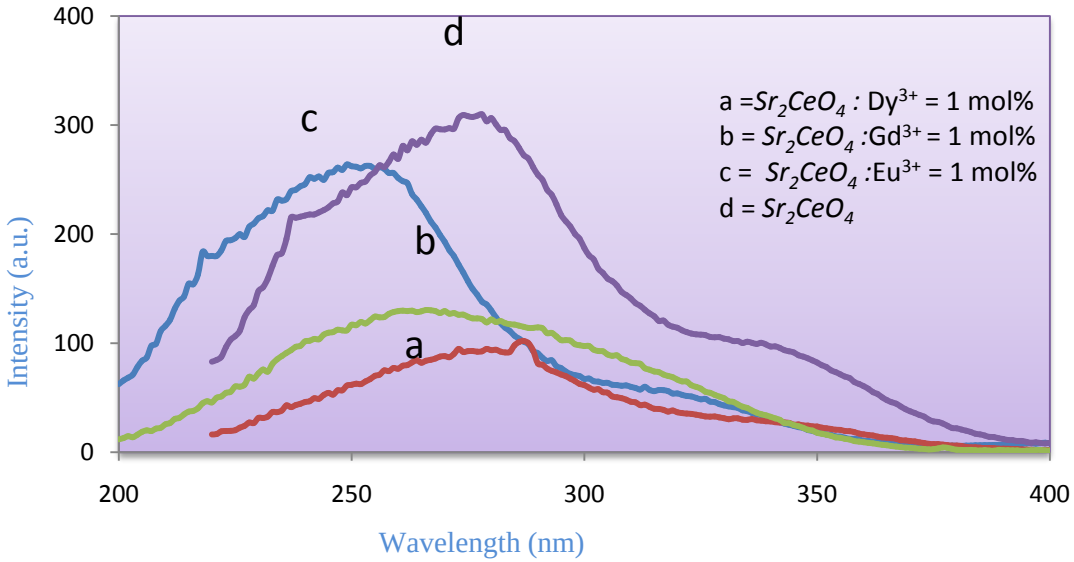


***Fig.3: Excitation spectra of $Sr_2CeO_4$ at different rare earth ions.***

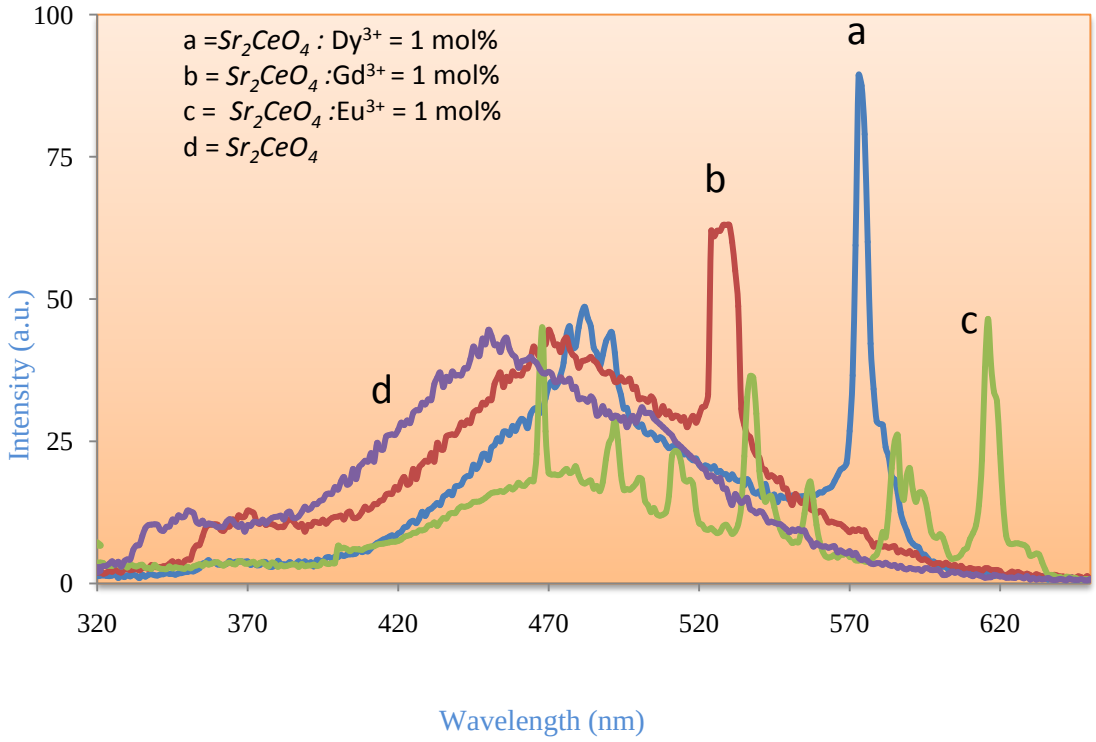


***Fig.4: Emission spectra of $Sr_2CeO_4$ at different rare earth ions doping, under 340 nm.***

Prepared all three sample shows same position peaks at blue region at around 470 nm, where as $Dy^{3+}$ doped $Sr_2CeO_4$ gives elevated intensity extra peak at 573 nm at orange-yellow region , $Gd^{3+}$ doped $Sr_2CeO_4$ gives additional high intensity peak at 527 nm at green region and $Eu^{3+}$ doped $Sr_2CeO_4$ gives one high intensity peak at 615 nm. So using these three samples we can form a day light emitting LEDs under commercial available NUV stimulating source. By combining primary colors, red, blue and green, we can form secondary colors yellow, cyan, and magenta [26]. Thus by blending above three samples which emit various flexible colors, we can produce better white light using phosphor-converted conventional RGB method. We also can control the exact requirement of white light which one can use according to the need also.

The luminescence peaks of different rare earth doped $Sr_2CeO_4$ are summarized in table(1), which shows that $Sr_2CeO_4$ is one of the smart material which shows different crystalline size from nanometer to micrometer range and tunes to different emission depends on types of impurities and method of preparation. Since, rare earth doped $Sr_2CeO_4$ doped sample emit light in blue to yellow-orange red spectral, which is sweet spot for photosynthesis, thus such white light emitting material may use for horticulture applications[10,25].

| **Sample** | **Method of preparation** | **Excitation wavelength (nm)** | **Emission peaks (nm)** | **Average crystalline size** | **Reference** |
|---|---|---|---|---|---|
| $Sr_2CeO_4$: $Eu^{3+}$ | Combustion | 340 | 462, 492, 513, 538, 557, 586, 613 | 720 nm | Fig.(3) |
| $Sr_2CeO_4$: $Dy^{3+}$ | | 340 | 482, 574 | | |
| $Sr_2CeO_4$: $Gd^{3+}$ | | 340 | 471, 530 | | |
| $Sr_2CeO_4$:$Eu^{3+}$, $Tb^{3+}$ | Solid state method | 254 | 467, 491, 511, 538, 557, 586, 616 | 32 nm | [19] |
| $Sr_2CeO_4$: $Sm^{3+}$ | Solid state method | 320 | 387,474,556, 611, 653 | 68 nm | [20,21] |
| $Sr_2CeO_4$:$Eu^{3+}$, $Sm^{3+}$ | Solid state method | 300 | 467, 492, 511, 538, 556, 567, 585, 616, 650 | -- | [22] |
| $Sr_2CeO_4$:$Er^{3+}$ | Solid state method | 226 | 527, 536, 552 , 558 | 35 nm | [21] |
| $Sr_2CeO_4$: $Gd^{3+}$ | Solid state Diffusion | 254 | A broad band with peak at 470 nm | 38 nm | [23] |
| $Sr_2CeO_4$: $Ho^{3+}$ | Solution combustion | 450 | Broad band from 524 to 574 and low intensity broad band from 630 to 670 | nanocrystalline particles | [25] |
| $Sr_2CeO_4$: $Eu^{3+}$ | Precipitation | 360 | 468, 492, 512, 538, 557, 586, 596, 616 | 6 to 9 µm | [11] |

***Table(1): Effect of rare earth on emission peaks in $Sr_2CeO_4$ phosphors.***

## 4. CONCLUSION

PL studies of $Sr_2CeO_4$ phosphors with rare earths $Gd^{3+}$ , $Dy^{3+}$ , $Eu^{3+}$ doped separately prepared by modified easy combustion method are presented in this article. XRD pattern of $Sr_2CeO_4$ phosphor reveals the triclinic single phase crystal structure of $Sr_2CeO_4$. SEM images of $Sr_2CeO_4$ shows agglomerated particles with irregular surfaces and non uniform morphology and average size of 705 mm. $Sr_2CeO_4$ with different rare earths doping shows same position peaks at blue region at around 470 nm, whereas, $Sr_2CeO_4$:$Dy^{3+}$ gives high intensity extra peak at 573 nm at orange-yellow region, $Gd^{3+}$ doped $Sr_2CeO_4$ gives extra high intensity peak at 527 nm at green region and $Eu^{3+}$ doped $Sr_2CeO_4$ gives one high intensity peak at 615 nm. So by blending these three samples which emit blue-green-orange-red color, one can be use as a good efficient phosphor-converted white light emitting material under commercial available NUV exciting source.

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