Thermoluminescence and Kinetic Parameters of $Y_2Zr_2O_7:Gd^{3+}$ Phosphor

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Abstract : Yttrium zirconate $Y_2Zr_2O_7:Gd^{3+}$ doped phosphors were successfully made using the solid state reaction method at 1350^0C for three hours. The structure and morphology were studied using scanning electron microscopy (SEM) and X-ray diffraction (XRD). Thermoluminecsence properties were assessed at room temperature by irradiating with UV radiation at a heating rate of 50Cs-1, peaking at 159^0C. The results are described in detail. Kinetic parameters including activation energy, frequency factor, and trap depth were determined using Chen's glow peak method. According to the findings, the produced phosphors provide a source of components for dosimetric applications.

Keywords : Solid-state method, XRD, thermoluminescence.

1.1 Introduction

Due to their special and increased features, rare earth oxides and rare earth doped phosphors have been the focus of much study to improve their bright qualities, which are crucial in the field of high-performance luminescent devices. Because of their broad spectrum of emission colours and strong luminous performance, RE ionactivated phosphors have received a lot of interest from manufacturers of luminescent materials.[1-5]. Many commercially useful rare earth doped phosphors have been studied extensively over the past three decades. Examples include cathode ray tubes, rare earth doped ZnS2, and Y_2O_3:Eu used in fluorescent lighting (CRT)[6-7].

Since there are no alternatives for rare earth elements since they exhibit the distinct electrical, magnetic, and optical features, rare earth phosphors and rare earth doped phosphors are regarded as an incredibly definite option in this way. This research uses $Y_2Zr_2O_7:Gd^{3+}$. Phosphors were created using the solid state reaction technique, and their TL properties were examined. The prepared phosphors were examined using the XRD technique, surface morphological analyses were conducted using SEM and TEM pictures, and crystalline formation was examined using EDS spectroscopy[8].

1.2 EXPERIMENTAL

High temperatures were used in a solid-state method to create the Gd3+ doped $Y_2Zr_2O_7$. When creating $Y_2Zr_2O_7$, the following materials were used: To produce Y_2O_3 (Yttrium (III) Oxide purity > 99.99 percent), ZrO_2 (Zirconium Oxide purity > 99 percent), Gd_2O_3 (Gadolium Oxide purity > 99.99 percent) as an activator, and H_3BO_3 (as a flux). In an hour, an agate mortar and pestle are used to pound all the ingredients into a fine powder in a stoichiometric amount according to commercial availability. Alumina was used as the crucible, and the grounded phosphor was heated in a muffle furnace at a rate of 5.0°C/min from room temperature to 1350°C.

The material was maintained at a temperature of 350°C for more than 3 hours. The furnace was then shut off so that the space could get to room temperature. The produced phosphor was then put into powder form after being dry ground to achieve homogeneity. X-ray diffraction (XRD) is used to characterise the sample using a PanalyticalXpert PRO MPD and a copper k alpha anode with a wavelength of 1.5405 Angstrom.

1.3 RESULT AND DISCUSION

1.3.1 *XRD STUDY*

In $Y_2Zr_2O_7$ with 1.5 mol% Gadolinium (III), Fig. 1 compares the observed and computed XRD pattern. The cubic structure creation with the space group of F d -3 m (227) appears to be in good accord with the diffraction peaks that were matched with COD card 96-152-8995 [11–13]. The COD card used was reported from $La_2Zr_2O_7$, even if the Crystallographic Open Database with the data corresponding to $Y_2Zr_2O_7$ phase is still not accessible for comparison. From the website http://www.crystallography.net/, the crystallographic information file 1528994.cif for the Crystallographic Open Database 96-152-8995 was downloaded. [14-15-17]. Scherrer's Equation estimates that the average crystalline size is around 44.37 nm, and TEM analysis for particle sizing confirms this[18].

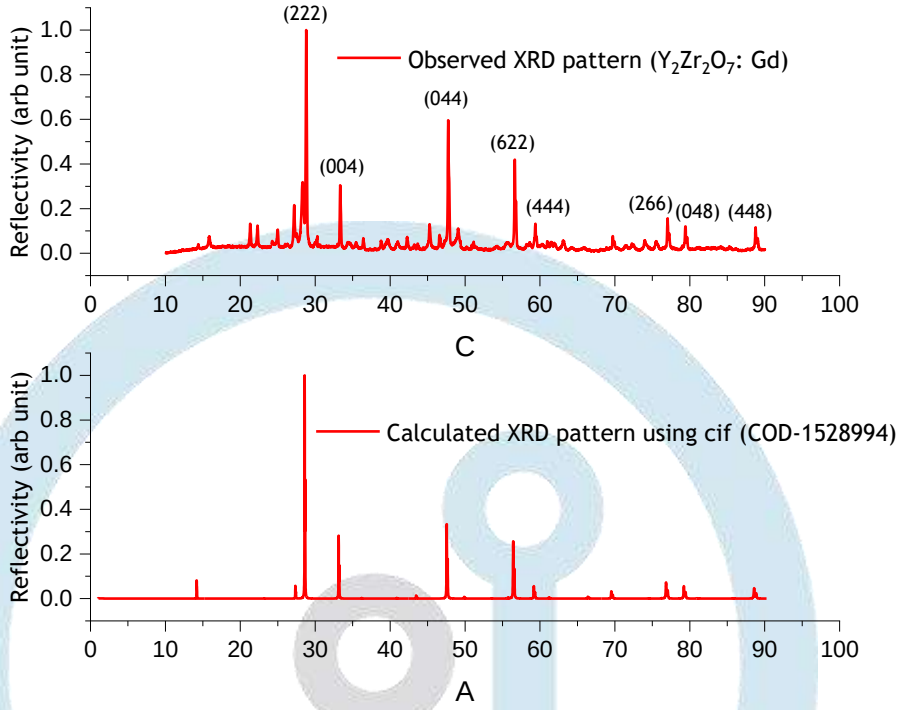

Fig. 1. Observe and Calculated XRD pattern of $Y_2Zr_2O_7$:Gd^{3+} phosphor of 1.5mol%.

1.3.2 SEM of prepared samples and EDS spectrum

A scanning electron microscope can be used to examine the microstructures of samples, including their surface roughness, composition, and other characteristics (SEM). The surface morphology of the ready sample, phosphor, is shown in Fig. 2(A). The SEM images of the phosphors are displayed in Fig. 2(A). The phosphor generated during the procedure was examined using a scanning electron microscope to determine the size and shape of the grains (SEM). From these photos, it is clear that the phosphor, $Y_2Zr_2O_7$, which has a dopant concentration of 1.5 mole%, has irregularly shaped particles of diverse sizes that are tightly agglomerated.

The particles are obviously slightly densified based on the SEM scans. Contrarily, the surfaces and grain size distribution of these crystallized particles are uniform. The typical particle has a spherical morphology and a diameter of a few micrometers[19]. In fig. 3, the EDS spectrum for the $Y_2Zr_2O_7$:Gd^{3+} phosphor is displayed.

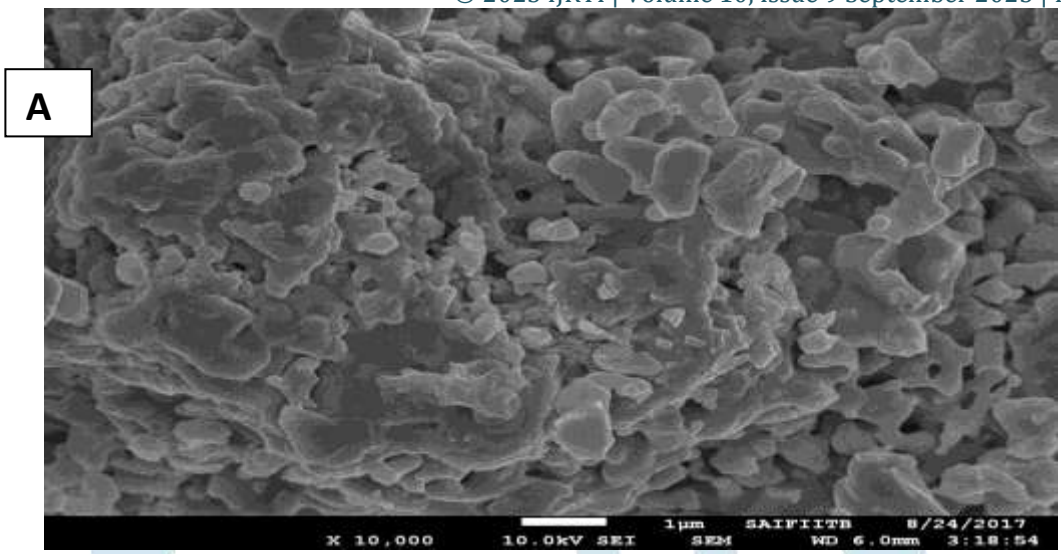

Fig. 2(A) SEM images of prepared $Y_2Zr_2O_7:Gd^{3+}$ phosphor of 1.5mol%.

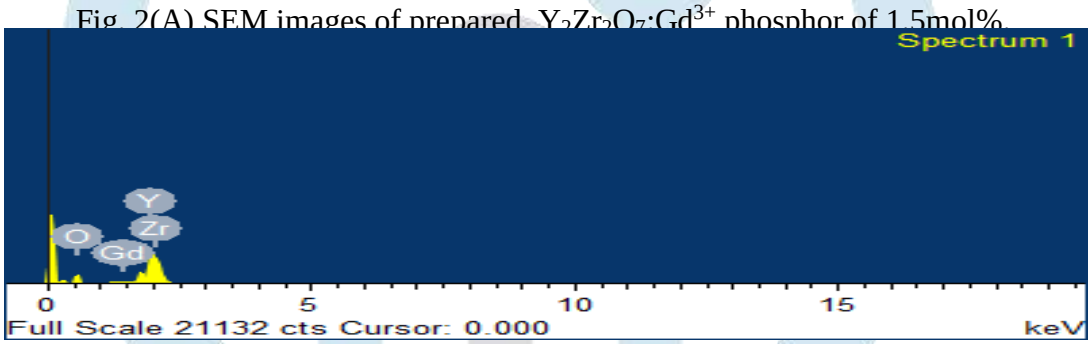

Fig. 3 The EDS spectra corresponding to the of $Y_2Zr_2O_7:Gd^{3+}$ phosphor

1.3.3 TEM analysis $Y_2Zr_2O_7:Gd^{3+}$ phosphor

The size and structure of the produced $Y_2Zr_2O_7$nanocrystals were directly determined by TEM. In Fig. 4, a typical TEM image is seen The $Y_2Zr_2O_7$ crystals, which resemble spheres, exhibit good miscibility. The average size of $Y_2Zr_2O_7$ as discovered by TEM is smaller than previously reported series and ranges between 50 and 100 nm. A typical HRTEM image can be seen in Figure 5. It demonstrates the particles' orientation within the crystal lattice and supports the creation of nano-polycrystals[20].

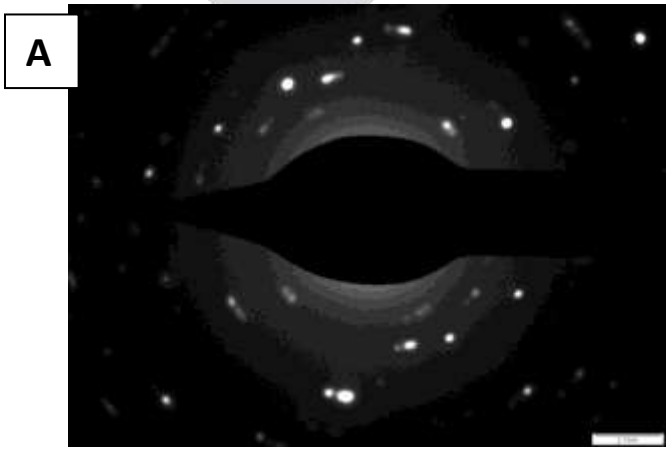

Fig. 4(A) TEM images of prepared $Y_2Zr_2O_7:Gd^{3+}$ phosphor of 1.5mol%.

1.3.4 Thermoluminescence study

There are numerous methods for evaluating the trapping parameters from TL glow curves. Here, we employed a heating rate of 50Cs-1 and the glow curve peak form method with varying UV exposure times. The peak shape method was used to estimate the activation energy and order of kinetics using Chen's empirical formula[19–20]. Two peaks were seen in the TL glow curve depicted in figure 5.1, with the intensity of the $Y_2Zr_2O_7:Gd^{3+}$ phosphor changing with time. The TL glow intensity of Gd3+ doped $Y_2Zr_2O_7$ phosphor is high.

The activation energies for the first peak vary from 0.23 to 0.30 eV and the second peak from 0.58 to 0.67 eV. The frequency factors for the first peak range from 3.01 to 5.92 eV per second and for the second peak from 4.68 to 7.34 eV per second, respectively. The trap depth was determined using the peak shape method, and the results are provided in Table 5.1 for the first peak, which ranges from 0.2369 eV to 0.4033 eV, and the second peak, which ranges from 1.0396 eV to 1.3866 eV.

According to Table 5.1's findings, every UV exposure has first order kinetics. This suggests that the traps are deeper and that we can anticipate this material to have afterglow characteristics. The thermoluminescence light curve may show two peaks, which indicates the creation of two traps at various trap depths [21-22].

According to Table 5.2, the peak's activation energy is up to 0.42eV to 0.44eV, its frequency factor is up to 1.42106 s-1 to 2.831011 s-1, and its trap depth was computed using the peak shape method and was discovered to be between 0.561eV and 1.004eV.

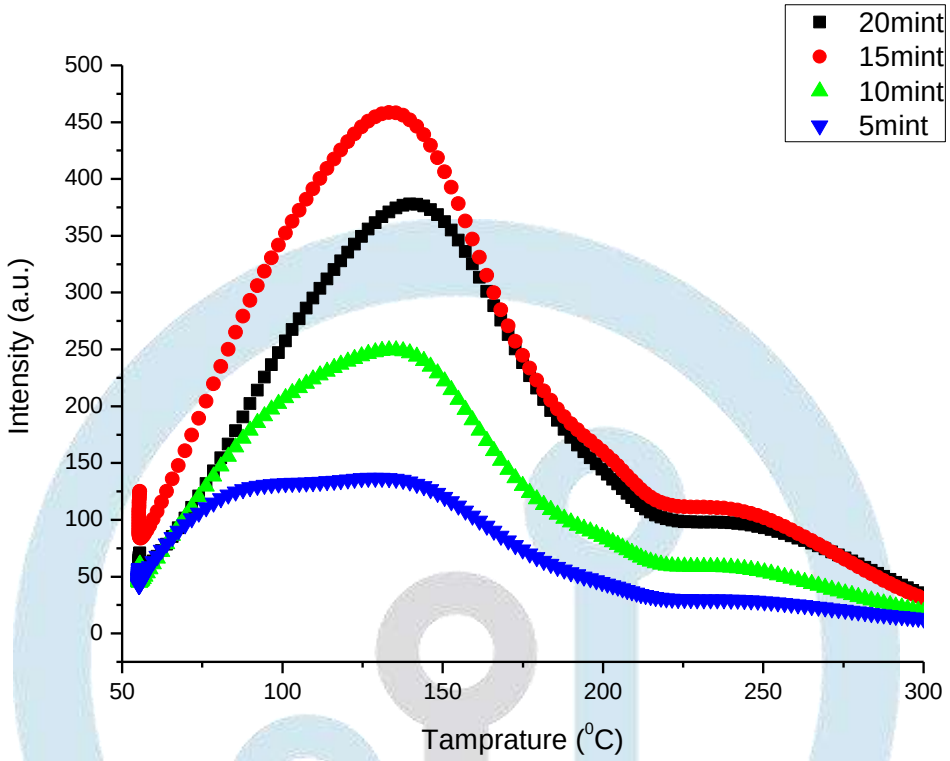

Figure 5.1 shows the TL glow curves for various UV exposures when Gd is doped with 0.1mol% $Y_2Zr_2O_7:Gd^{3+}$ phosphor.

Table 5.1 Calculation of shape factor, activation energy, frequency factor and Lifetime of charg

UV Min	Peak	T_1 (°C)	T_m (°C)	T_2 (°C)	T_1 (K)	T_m (K)	T_2 (K)	τ	δ	ω	μ = δ/ω	Activation Energy		Frequency Factor
												First Order	Second Order	
5	1	61.26	130.60	178.60	334.42	403.76	451.76	69.34	48.00	117.34	0.41	0.23	0.35	3.01×10^{3}
	2	215.93	242.60	291.66	489.09	515.76	564.82	26.67	49.06	75.73	0.65	0.67	0.98	7.34×10^{8}
10	1	74.77	133.44	176.11	347.93	406.60	449.27	58.67	42.67	101.34	0.42	0.28	0.42	2.68×10^{4}
	2	201.71	237.97	278.51	474.87	511.13	551.67	36.26	40.54	76.80	0.53	0.64	0.94	4.18×10^{8}
15	1	79.40	133.80	178.60	352.56	406.96	451.76	54.40	44.80	99.20	0.45	0.29	0.44	3.81×10^{4}
	2	205.26	234.06	281.40	478.42	507.22	554.56	28.80	47.34	76.14	0.62	0.64	0.94	4.31×10^{8}
20	1	87.57	140.91	185.71	360.73	414.07	458.87	53.34	44.80	98.14	0.46	0.30	0.46	5.92×10^{4}
	2	203.84	237.97	288.11	477.00	511.13	561.27	34.13	50.14	84.27	0.59	0.58	0.85	4.68×10^{7}

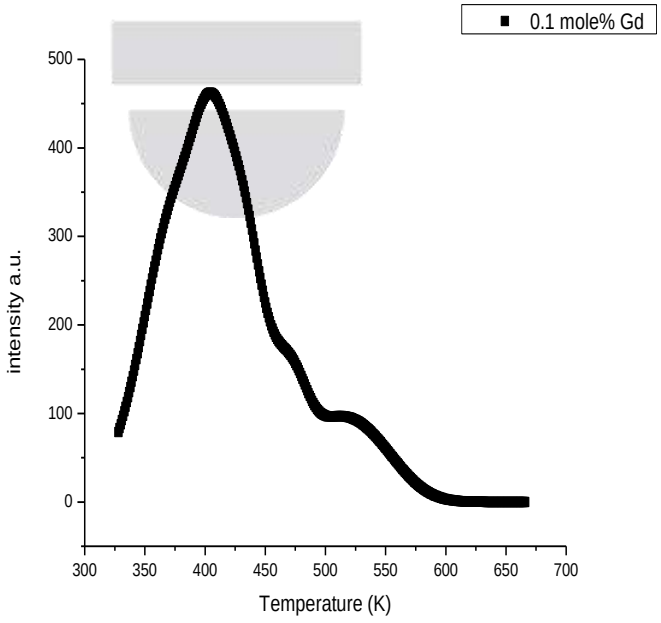

Figure 5.2 (a) TL glow curve 0.1mol% 15min UV irradiation

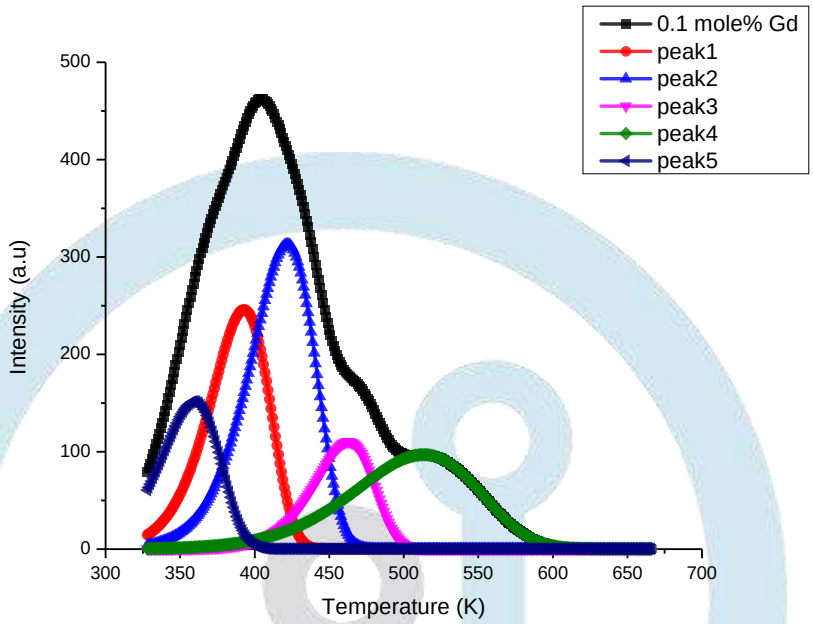

Figure 5.2 (b) TL glow curve 0.1mol% 15min UV irradiation deconvulated glow curve

Table 5.7.2 Shape factor, activation energy, frequency factor, and charge lifetime in the trap are all calculated

Peak	T_1 (°C)	T_m (°C)	T_2 (°C)	T_1 (K)	T_m (K)	T_2 (K)	τ	δ	ω	μ = δ / ω	Activation Energy		Frequency Factor
											First Order	Second Order	
1	92.61	119.28	139.55	365.77	392.44	412.71	26.67	20.27	46.94	0.43	0.64	0.93	2.83×10^{11}
2	119.28	149.15	170.48	392.44	422.31	443.64	29.87	21.33	51.20	0.42	0.68	0.98	1.74×10^{11}
3	162.12	189.86	210.12	435.28	463.02	483.28	27.74	20.26	48.00	0.42	0.88	1.27	2.58×10^{13}
4	184.17	240.70	284.44	457.33	513.86	557.60	56.53	43.74	100.27	0.44	0.48	0.71	1.42×10^{6}
5	59.55	86.21	106.48	332.71	359.37	379.64	26.66	20.27	46.93	0.43	0.53	0.77	2.37×10^{10}

Thermoluminescence (TL) light curve displays the alarming flaws brought on by ionising radiation exposure. The glow curve refers to the measurement of luminescence intensity as a function of changing temperature and previously exposed material. The intensity of the thermoluminescence emission increases up to 1mol% as the dopant concentration rises, after which it falls due to a non-radiative transition. The TL shining curves with variations in Gd^{3+} concentration are given here, with the heating rate utilised for TL measurements being 5^0Cs-1. The TL intensity rises with increasing Gd^{3+}

concentration up to 1mol%, after which concentration quenching takes place and the trap centres are destroyed, causing a decrease in the intensity of the thermoluminescence glow curve.

1.3.5 Conclusion

$Y_2Zr_2O_7:Gd^{3+}$ doped phosphor was created at 1350^0C by a solid state reaction technique. The results of the XRD, SEM, and TEM studies used to describe the phosphor revealed that its size is in the micrometre range. The produced phosphor's order of kinetics and kinetic parameters including activation energy and trap depth were estimated using TL analysis. When the concentration of Gd^{3+} ions is increased while maintaining TL intensity of 0.1mol% Gd doped higher at 159^0C, the intensity decreases. The TL intensity is very high in linear gamma exposure, and the order of the kinetic parameters is first order. The synthesised phosphors are therefore fully functional in dosimetric applications.

Declaration of competing Interest

I hereby declare that this manuscript is our pure and experimental work. there is no any confilt of interest.

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References

[1] W. Li, A.I. Frenkel, J.C. Woicik, C. Ni and S.I. Shah, Physical Review Letters, B 72 155315 (2005).

[2] Z. Zhou, T. Komori, T. Ayukawa, H. Yukawa, M. Morinaga, A. Koizumi and Y. Takeda, Applied Physics Letters, 87 091109 (2005).

[3] Y.P. Li, J.H. Zhang, X. Zhang, Y.S. Luo, X.G. Ren, H.F. Zhao, X.J. Wang, L.D. Sun, and C.H. Yan, Journal of Physical Chemistry C, 113 4413 (2009).

[4] J. Lin, M. Yu, C.K. Lin and X.M. Liu, Journal of Physical Chemistry C, 111 5835 (2007).

[5] M.A.J. Klik, T. Gregorkiewicz, I.V. Bradley, and J.P.R. Wells, Physical Review Letter, 89 227401 (2002).

[6] J.M.P.J. Vestegen, Journal of the Electrochemical Society, 121 (22) 1623 (1974).

[7] C. R. Ronda, Journal of Alloys and Compounds, 225 534 (1995).

[8] V. Lupei, N. Pavel, and T. Taira, Applied Physics Letters, 81 (15) 2677-2679 (2002).

[9]. Ramadhin, Jagjeet K. Saluja, Ravi shrivastava, Vikas Dubey, Optik Volume 260, June 2022, 169082, https://doi.org/10.1016/j.ijleo.2022.169082.

[10] Dhas, N. A., Patil K. C. J Mater Chem 3, 1289-1294 (1993)

[11] Yamamura H. , Nishino H. , Kakinuma K. J. , Phys Chem Solids 69, 1711-1717(2008)

[12] Marc Jovaní, Ana. Sanz, Hector Beltran-Mir., Eloisa Cordoncillo, Dyes and Pigments 133, 33-40(2016)

[13] Qingqing Du, Guangjun Zhou et al. Journal of Alloys and Compounds 552 , 152-156(2013)

[14] Ramadhin, et. al. "Photoluminescence properties of Gadolinium doped Yttrium Zirconate Phosphors for Optoelectronic Applications." International Journal of Engineering Science Invention (IJESI), Vol. 11(06), 2022, PP 16-22. Journal DOI- 10.35629/6734

[15] Dhas, N. A., Patil K. C. J Mater Chem 3, 1289-1294 (1993)

[16] Yamamura H. , Nishino H. , Kakinuma K. J. , PhysChem Solids 69, 1711-1717(2008)

[17] Marc Jovaní, Ana. Sanz, Hector Beltran-Mir., Eloisa Cordoncillo, Dyes and Pigments 133, 33-40(2016)

[18] Qingqing Du, Guangjun Zhou et al. Journal of Alloys and Compounds 552 , 152-156(2013)

[19] Ran Huang , Sai Li , Shaolin Xue, Zhixing Jiang , Shuxian Wu International Conference on Future Environment and Energy IPCBEE vol.28(2012) © (2012)IACSIT Press, Singapoore.

[20] Yuping Tonga, Panpan Xuea, Fangfang Jianb, Lude Lua,∗, Xin Wanga, Xujie Yanga, Materials Science and Engineering B 150 (2008) 194–198]

[21] R. Kalai Selven, A. Gedankken, P. Anilkumar et al. J Clust Sci 20, 291-305(2009).

[22]20.V. Dubey, J. Kaur et al. Opt. Int. J. Light Electron. Opt. (2013), http://dx.doi.org/10.1016/j.ijleo.2013.03.153.