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Evaluation of Eu/Dy ratio on Nd-doped SrAl₂O₄ and their role on luminescence properties

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The purpose of this study was production of photoluminescent pigments by adding different ratios of Eu/Dy to SrAl₂O₄: Nd³⁺ composites. Presence of Eu and Dy in the pigments, alone or together causes varying fluorescence and phosphorescence properties regarding their emission intensity and afterglow length. The resulted differences in morphology and crystal structure of these pigments were measured by spectroscopic methods. The interesting fact in this work is the emission type of the pigments before and after the reduction process; as the pigments were white powders showing strong red emission under UV irradiation and after the reduction process, they showed strongly visible afterglows. Six samples with different Eu/Dy ratios were synthesized and named samples N1 to N6. They underwent the thermal reduction process and the resulting samples were named N1A to N6A. The phosphorescence analysis showed an intensity count of 518 for sample N6A, the fluorescence showed an intensity of 797 counts for sample N6A, and the sample N4A showed an afterglow time of about 5 h with a strong initial afterglow of about 20 minutes.

Key words: Microwave synthesis, Phosphorescence, Fluorescence, Dopant Phosphors.

Introduction

Luminescence is the emission of light from any type of sources except hot sources resulted from some phenomena including pressure on the crystal, electron beams, etc. Photoluminescence is a type of luminescence in which photons cause excitation of the electrons to higher states and consequently an emission during the relaxation process. If the emission radiation is emitted immediately, the process is called fluorescence and if the emission has a delay, it is called phosphorescence. Phosphors are materials which demonstrate fluorescence or phosphorescence phenomenon.

Phosphors with luminescence properties were produced for the first time in the 20th century including zinc sulfides which were doped with other dopants such as Cu and Mg. Afterward, some other dopants were added to the composites of ZnS as co-dopants such as cobalt. Then, ZnS was replaced by other alkaline earth metals such as CaS and SrS in addition to other dopants including Ce³⁺ and Eu³⁺ [1] until strontium aluminates were introduced to the world. Europium-doped strontium aluminates are novel compounds with long-lasting afterglow in comparison with common Cu doped ZnS pigments [2-5]. There are six types of well-known phosphors among the strontium aluminates including $Sr_2Al_6O_{11}$, $Sr_4Al_{14}O_{25}$, $Sr_3Al_2O_6$, $SrAl_4O_7$, $SrAl_{12}O_{19}$,

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and SrAl₂O₄ [6], among which SrAl₂O₄ has been broadly investigated due to its acceptable afterglow and the wide charge transferability. Eu doped SrAl₂O₄ systems are introduced by Palilla et al. as they declared that this material shows a greenish emission glow peak at 520 nm [1, 2, 7, 8]. Long persistent afterglow SrAl₂O₄: Eu²⁺, Dy³⁺ was introduced by Matsuzawa in the 1990s, demonstrating the fact that the presence of Dy extremely enhances the afterglow property [1, 7-11] due to the hole-electron mechanism [1, 2, 4, 14]. A. H. Wako et al. introduced a laser synthesized SrAl₂O₄: Eu^{2+} , Dy^{3+} , Nd^{3+} reporting a high PL intensity [3]. Tadashi Ishigaki et al. (2007) synthesized SrAl₂O₄: Eu²⁺, Dy³⁺ using carbon reduction and microwave irradiation [12].

There are different techniques to synthesize these materials such as solid state reaction [1, 2, 3, 6], sol-gel [1, 2, 4, 7], reverse micro-emulsion [1, 8], and solution combustion synthesis (SCS) [1-4, 6, 9]. Among these techniques, the SCS is one of the most reliable and convenient techniques to synthesize nanomaterials due to its facility, affordability, provided small crystal size, being energy saving, and being fairly safe. Consequently, as explained above, the most improved method is the SCS and the most effective initial materials are Eu^{2+} , Dy^{3+} , Nd^{3+} doped $SrAl_2O_4$.

In this work which is a modified study derived from Tadashi Ishigaki et al., we investigated the effect of Eu and Dy concentration on the luminescence properties of the synthesized pigments in the presence of Nd as co-dopant and boric acid and found an optimized concentration of these dopants. Also, we had a meticulous

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investigation of XRD and photoluminescence analysis of the samples before and after the reductive furnace.

Materials and Methods

Starting materials were $Sr(NO_3)_2(99 \%)$, $Al(NO_3)_3$. 9H₂O, (99 %), Eu(NO₃)₃·6H₂O, Dy(NO₃)₂·5H₂O, Urea, Nd(NO₃)₃·6H₂O, Boric acid, and water. The mass ratios of the initial materials are presented in Table 1. Enough water was added to the dry nitrates in a small flask. After a complete stir on a heater, a clear gel was formed. This gel was introduced into a crucible and it was taken into the microwave oven and the combustion reaction started. The reaction took almost 5 minutes to accomplish in the microwave oven. Gases (mainly oxides of nitrogen, carbon, and ammonia) resulted from the drastic combustion of nitrates erupted during the process. The fluffy brittle foam was taken out, lightly crushed down, and sieved for the analysis process.

The samples N1, N2, N3, N4, N5, and N6 were afterward introduced into a reductive furnace on boat crucibles where the pure hydrogen gas with atmospheric pressure passed over the powders while they were being heated up to 1350 °C for one hour. The samples shrunk extremely due to the burning out of excessive nitrates. The measured mass was decreased by approximately 40% after the reduction process. The samples after the reduction process were called samples N1A, N2A, N3A, N4A, N5A, and N6A.

XRD spectroscopy was carried out using the STOE STADI P, 40 kV, and 30 mA spectrometer with Cu lamps. SEM imaging was implemented using the Zeiss FE-SEM model SIGMA VP SEM microscope. FTIR spectroscopy carried out using Thermo Nicolet 8700 IR spectrometer, and luminescence spectroscopy was done using the Perkin Elmer LS 55 fluorescence spectrometer. These analyses were performed on each sample before and after undergoing the reduction-heat process. The reduction process was performed in a controlledatmosphere tube furnace as it can be seen in Fig. 1.

Results and Discussion

XRD result analysis

The prepared samples, before and after the reductive furnace own distinctive phases. These phases have been recognized by XRD analysis. The following tables demonstrate detailed data such as observed and standard 2θ s belonging to the samples. The crystal sizes have been calculated according to the Scherrer equation:

$$d_c = \frac{k\lambda}{\beta\cos\theta}$$

Where k is the constant of proportionality (Sherrer constant, also called shape factor, usually equal to 0.94) which depends on the shape of the crystal, how the width is determined, and the size distribution. λ is the X-ray wavelength. β is the line broadening at half the maximum intensity (FWHM) in terms of radians, and θ is the Bragg angle in terms of degrees.

Most of the prepared samples are composed of $SrAl_2O_4$; therefore, the total crystal size is nearly the same as the $SrAl_2O_4$ phase.

Fig. 2 demonstrates the XRD graph of samples N1 and N1A. The process was the conversion of N1 to N1A in

Samples	Eu(No ₃) ₃ .6H ₂ O	Dy(NO ₃) ₃ .6H ₂ O	Sr(NO ₃) ₂	H ₃ BO ₃	Urea	Nd	Al(NO ₃) ₃ .9H ₂ O
1	0	0	1	0.06	4	0.02	3.74
2	0	0.04	1	0.06	4	0.02	3.74
3	0.02	0.04	1	0.06	4	0.02	3.74
4	0.04	0.04	1	0.06	4	0.02	3.74
5	0.02	0	1	0.06	4	0.02	3.74
6	0.02	0.08	1	0.06	4	0.02	3.74

Table 1. Constituents mass of precursor samples (g).







Fig. 2. Detailed XRD analysis of samples N1and N1A where 1 represents $SrAl_2O_4$, 2 represents $Sr_4Al_{10}O_{23}$, 3 represents $Sr(NO_3)_2$, and 4 represents $SrAl_4O_7$.

which the hexagonal phase converted to monoclinic after undergoing reduction furnace with 1350°C heat. Intensities of $2\theta = 28.38$ and $2\theta = 29.92$ peaks belonging to the monoclinic phase have significantly increased from the samples N1 to N1A. The peak of $2\theta = 19.76$ belonging to Sr(NO₃)₂ phase had a significantly dropped intensity in N1A. The SrAl₄O₇ phase in $2\theta = 25.17$ in N1has totally disappeared in N1A, but new peaks of Sr₄Al₁₀O₂₃ had appeared in $2\theta = 31.40$ in N1A.

Table 2 demonstrates the detailed XRD analysis of samples N1, N2, N3, N4, N5, N6, N1A, N2A, N3A, N4A, N5A, and N6A, respectively. Notice that standard angles and standard intensities vary in different samples since there are different properties in some compounds. For instance, SrAl₂O₄ has two different monoclinic phases with different cell sizes and/or cell corner angles. Such differences occur in some other compounds as well.

Table 3 demonstrates the simplified constituting phase comparison between the samples before and after the reduction/calcination process.

Photoluminescence result analysis

Afterglow analysis

Afterglow stimulation was performed with a white LED light owning the light intensity of 24000 lux for 30 seconds. The samples which underwent the reductive

Table 2. Detailed XRD analysis of phases of the samples N1,N2, N3, N4, N5, N6, N1A, N2A, N3A, N4A, N5A, and N6A.

Phases Observe 2θ angl		Observed intensity	hkl	Standard 2θ angle	Standard intensity	Crystal size (nm)	
	41.82	7.44	231	41.86	14		
SrAl ₂ O ₄	42.88	12.85	400	42.89	21	52	
	56.26	2.58	-332	56.42	8		
	25.54	23.48	210	25.57	25		
	28.01	22.65	211	28.06	16		
	32.43	16.57	220	32.49	20	37	
$Sr(NO_3)_2$	38.18	42.28	311	38.33	65		
	40.00	47.68	222	40.13	55		
	52.41	7.84	420	52.55	10		
	14.47	3.83	110	14.53	9		
	20.05	55.66	020	20.10	27		
0.41.0	28.41	53.45	-211	28.38	100	00	
$SrAl_2O_4$	29.29	81.05	220	29.27	91	80	
	35.14	52.48	031	35.11	69		
	37.29	8.96	131	37.04	16		
	24.23	6.44	-220	24.31	29		
	25.13	20.93	-311	25.17	100		
SrAl ₄ O ₇	27.26	5.55	-221	27.24	21	81	
	30.56	5.67	130	30.58	23		
	31.88	10.89	221	31.88	23		
	18.18	7.23	001	18.14	23.9		
	21.02	3.64	020	20.96	10.80		
SrAl ₄ O ₂	25.41	16.70	420	25.42	96.2	75	
	31.38	17.27	421	31.40	100		
	34.19	18.88	801	34.24	55.7		
Dy ₂ O ₃	78.40	3.66	662	78.35	5.7	49	
EuSrAl ₃ O ₇	34.20	8.60	801	34.24	55.7	86	
Sr ₄ Al ₄ O ₂	64.86	4.35	14-3- 1	64.95	28.9	23	
	33.95	9.49		33.92	100		
NdAlO ₃	71.05	3.51		71.09	25	43	
	89.93	9.93 3.99 89.93 6		6			
E. 410	27.87	10.52	111	27.87	100	24	
EuAlO ₃	32.17	2.57	200	32.28	37	24	
	25.38	5.41	101	25.04	60		
NA AIO N	32.21	5.51	103	32.30	100	65	
INd ₂ AIO ₃ IN	43.63	2.70	105	43.56	30	65	
	45.06	15.02	114	45.09	60		
Nd ₂ O ₃	31.44	8.74		31.38	70	98	
D. D	36.39	21.35	211	36.44	100	74	
DуВ ₄	73.16	12.75	412	73.15	13.6	/4	

furnace had the afterglow effect except for the samples N1A (without Eu and Dy) and N2A (without Eu). The sample with Eu but without Dy (N5A) showed the afterglow effect, while the sample with Dy and without Eu (N2A) did not. This approves this fact that the presence of Eu is the essential element of the phosphorescence effect. The sample N1A that lacks both Eu and Dy but has Nd did not have any afterglow, proving the necessity of Eu as the afterglow agent. On

Table 3. Simplified constituting phase comparison.

Samples	Constituting Phases						
N1	SrAl ₂ O ₄	$Sr(NO_3)_2$	SrAl ₄ O ₇				
N2	$SrAl_2O_4$	Sr(NO ₃) ₂	SrAl ₄ O ₇				
N3	$SrAl_2O_4$	$Sr(NO_3)_2$	SrAl ₄ O ₇				
N4	$SrAl_2O_4$	$Sr(NO_3)_2$					
N5	$SrAl_2O_4$	Sr(NO ₃) ₂					
N6	$SrAl_2O_4$	Sr(No ₃) ₃					
N1A	$SrAl_2O_4$	SrAl ₄ O ₂					
N2A	$SrAl_2O_4$	Sr ₄ Al ₄ O ₂					
N3A	$SrAl_2O_4$	$Sr_4Al_4O_2$	EuSrAl ₃ O ₇	Dy_2O_3	NdAlO ₃		
N4A	$SrAl_2O_4$	EuAlO ₃	NdO_2				
N5A	$SrAl_2O_4$	EuAlO ₃	NdAlO ₃ N				
N6A	$SrAl_2O_4$	DyB_4	Nd_2O_3				

the one hand, sample N6A had the highest intensity of afterglow as soon as the light source is cut off but on the other hand, it had the highest decay rate (Fig. 4). Sample N4A has the most afterglow intensity after a certain amount of time comparing to the others. The comparing curves are presented in Fig. 3.

The afterglow photos of sample N4A as the sample with the longest afterglow is presented in Fig. 4:

Fluorescence and phosphorescence emission analysis

In order to study the fluorescence effect, the emitted fluorescence beams were collected while the excitation laser beam was irradiated to the samples. In order to study the phosphorescence effect, the emitted phosphorescence beams were collected immediately



Fig. 3. Decay curve of samples N3A, N4A, N5A, and N6A.

after the excitation light source was cut off.

Samples before the reduction furnace

Fluorescence emission spectra with the excitation wavelength of 254 nm

In this case, the peaks are related to absorption and emission of the lattice. These lattices can provide an emission in the band gap region because of the presence of a sort of excitable band gaps, particularly at 254 nm. In a general look to Fig. 5, it seems that the 405 nm peak is related to the absorption and emission of the aluminate lattice. Another peak is being observed in 631 nm which can be because of defects in



Fig. 4. Afterglow pictures of the sample N4A in respective times of 0, 5, 10, 15, 20, 30, 180, and 300 min. Picture (a) demonstrates the sample in daylight.



Fig. 5. Emission curves of samples N1, N2, N3, N4, N5, N6, N1A, N2A, N3A, N4A, N5A, and N6A including fluorescence and phosphorescence curves after being exposed to 254 nm and 360 nm irradiation.

the lattice; however, europium can have a peak in this region, but due to the observation of a peak in the samples lacking europium (sample N1 and N2), this peak is attributed to lattice defects. This is natural because the technique used in this paper is combustion

synthesis and these samples did not undergo the reduction process; therefore, the samples have numerous defections. Defection is one of the major reasons for the formation of inter-state energy states in the band gap and consequent emissions. We should keep in mind that the inter-state energy states of Nd, B, Eu, and Dy can influence the relaxation transitions from the conductivity band to the valence band and that is why all of the samples show a lower intensity comparing to the N1 sample.

Fluorescence emission spectra with the excitation wavelength of 360 nm

As observed in Fig. 5, it seems that low-energy excitation with the wavelength of 360 nm led to an emission with a lower energy comparing to the excitation wavelength of 254 nm. This might have quantum mechanics reasons; in other words, because the materials were in the nano-scale before the thermal reduction process, the band gap was affected by the excitation beam. In this excitation, the effect of varied parameters on the intensity and even the emission frequency is more tangible. Generally, the lattice has a low-energy peak which refers to the spinel lattice of alumina.

Phosphorescence emission spectra with the excitation wavelength of 254 nm

As it can be observed in Fig. 5, there is a totally different result in the phosphorescence mode and the obtained curve was almost zero. The reason for this phenomenon can be the competition among formation of phosphorescence inter-states and defection inter-states (which are more active in the room temperature). Therefore, it can be inferred that any change in the pure strontium aluminate which has occurred, comparing to the sample N1, has caused the lower intensities. In other words, the formation of the defections or non-stoichiometric conditions leads to a competition between phosphorescence inter-state and defection inter-state, leading to low phosphorescence emission.

Phosphorescence emission spectra with the excitation wavelength of 360 nm

Regarding the comparison of UV low and high energy excitation beams, it was observed that the appropriate excitation beam is the low energy one. Basically, phosphorescence is observed while using low energy excitation beams. Three regions were be recognized in these curves. Based on the investigations, the phosphorescence mode is a result of the presence of Dy as its absence in samples N1 and N5 has led to an absolute disappearance of the three obvious peaks belonging to Dy. Sample N6 which had the most amount of Dy had the highest peak.

Samples after the reductive furnace

Fluorescence emission spectra with the excitation wavelength of 254 nm

As it is observed in Fig. 5, the curve intensities changed significantly after the reductive furnace. The reason is the competition between fluorescence and phosphorescence emissions. In other words, after the reduction process and growth of the particles in size after the reductive furnace, the Eu^{2+} triple energy states were formed, which are the responsible of the emission at around 520 nm. Therefore, the phosphorescence process took place more, comparing to the fluorescence. The absence of a peak at 610 nm was due to the reduction of Eu^{3+} to Eu^{2+} during the reduction process. As we know, the Eu^{3+} peaks can be seen in the excitation with the 254 nm UV beam. Also, the curve intensities increased significantly for these samples comparing to those belonging to the samples before the reductive furnace due to the more crystallization resulted from the calcination process.

Fluorescence emission spectra with the excitation wavelength of 360 nm

In this case, the interesting point in Fig5 was the similarity of this emission spectra with the one resulted from 254 nm excitation UV beams. However, there were differences in the position of the peaks due to the dopant effects. The modified lattice structure due to the calcination process led to this similarity in 254 nm and 360 nm fluorescence emissions.

Phosphorescence emission spectra with the excitation wavelength of 254 nm

According to the curves in Fig. 5, the samples demonstrated a significant phosphorescence after undergoing the reductive furnace. The simultaneous reduction and calcination process led to the production of the electron traps which provided the phosphorescence effect. The peak at 514 nm belongs to Eu^{2+} , which was not observed in samples N1 and N2 with no Eu content. The reduction process produced a green emission because of the presence of Eu^{2+} , but the afterglow is a result of the presence of Dy^{3+} . That is why even the sample without Dy (sample N5) had an acceptable initial phosphorescence emission but not a long afterglow.

Phosphorescence emission spectra with the excitation wavelength of 360 nm

The best phosphorescence emission was observed in this case. In fact, except the sample N1 and N2 with no Eu content, other samples had significant phosphorescence. The peak position is the same (513 nm) about both low and high energy excitation UV beams which confirmed the excellent crystallization of the samples during the heat treatment. The sample with the highest initial phosphorescence intensity was sample N6 with the most amount of Dy. Basically, a significant phosphorescence effect is a result of a proper balance between Eu and Dy.

In a general look at Fig. 5, it can be inferred that in the e, f, g, and h curves demonstrating the fluorescence and phosphorescence behavior of the samples after the furnace, the 520 nm emission attributed to the $4f^{6}5d$ to $4f^{7}$ transition of Eu²⁺ centers is the dominant one. The same emitted wavelength of 520 nm has been obtained from different studies [1-16] for SrAl₂O₄: Eu²⁺, Dy³⁺ pigments exposed to excitation beams. But here, as we see, we have obtained curves with different intensities but almost with the same wavelengths for different samples, which proves the role of dopants concentration in the intensities of luminescence emission as well as the afterglow effect. Fig. 5 demonstrates the emission curves of the analyzed samples in 254 nm and 360 nm irradiations.

Fig. 6 demonstrates samples under UV light with wavelengths of 254 nm and 360 nm.

IR results

In Fig. 7, symmetric and antisymmetric bendings and stretchings are being demonstrated. According to the

results, the stretching peak belonging to the metal oxides at around 3430 cm⁻¹ [16] had a significantly decreased intensity from samples before furnace to the samples after furnace.

The IR analysis obtained from all of the samples are fairly similar. The only change took place as a result of calcination process in which the IR curves had some drastic changes in some parts of the IR curve. Therefore, we use one of the results as follows in Fig. 7.

SEM result analysis

In Fig. 8, SEM imaging of each sample before and after the furnace is presented respectively. According to this figure, the heating process has totally changed the structures of the samples, from grainy particles to orderly stacked sheets with thickness average of 80 nm. Addition of Dy in sample N2 caused a partial particle agglomeration comparing to sample N1. Adding Eu



Fig. 6. Samples N1, N2, N3, N4, N5, and N6 before and after furnace under UV radiation of 254 nm and 360 nm.



Fig. 7. IR spectra of samples N1 and N1A where 1 is the antisymmetric bending of O-Al-O, 2 is the antisymmetric stretching of Al-O-Al, 3 is the symmetric stretching of O-Al-O, 4 is the vibrational stretching of BO₃ and BO₄, and 5 is the OH stretching.



Fig. 8. SEM imaging of the samples N1, N2, N3, N4, N5, N6, N1A, N2A, N3A, N4A, N5A, and N6A.

Table 4. EDS results of samples N1, N2, N3, N4, N5, N6, N1A, N2A, N3A, N4A, N5A, and N6A.

Samulas	wt% of elements							
Samples	В	Sr	0	С	Al	Eu	Dy	Nd
N1	18	19.8	22	22.3	17.2	0	0	0.7
N1A	18.1	20.4	18	20.9	17.3	0	0	0.8
N2	18	20.1	26.3	18.3	17.1	0	0	0.2
N2A	18.3	19.7	17.37	25.1	17	0.1	2.2	0.2
N3	18.1	19.5	22.9	17	17.2	0.6	3.7	1
N3A	18.2	19.4	23.4	0	17.3	0	21.6	0.1
N4	18.3	19.3	23.4	19	17.4	1.8	0.8	0
N4A	18	20.1	42.9	0	17.3	0.4	1.1	0.2
N5	18.1	19.8	28.3	16	17.1	1.1	0	0
N5A	18.2	20.2	44.6	0	17	0	-	0
N6	18.1	19.6	22.1	21	17.2	0.5	1.5	0
N6A	18.2	0	61.1	0	17.1	0.7	2.7	0.2

along with Dy in sample N3 caused more drastic agglomeration of particles. Increased concentration of Eu reversed effect this time in sample N4 as its particle size is even smaller than sample N1. The absence of Dy in sample N5 led to bigger particle sizes. Doubling Dy concentration also led to fairly big particle sizes in sample N6.

EDX results

EDX results approve the presence of the elements used in this study according to Table 4.

Conclusion

According to the results obtained from afterglow analysis, the presence of Eu caused the sample to demonstrate afterglow properties, but the presence of Dy did not cause afterglow and enhanced it to some extent. Actually, the more Dy was added, the more initial afterglow intensity was observed, but it reduced the afterglow length at the same time, as in sample 4 which did not have the highest Dy amount, it showed the longest afterglow. The luminescence analysis and the UV-box light photos approved these results. Adding Eu in the samples also caused a red glow under UV light with the wavelength of 254 nm before the samples undergo the calcination/reduction process. This fluorescence emission is attributed to structural deficiencies in the samples which is the reason for emission after excitation with UV radiation. After the calcination/reduction process, the Eu³⁺ ions reduce to Eu^{2+} and the $4f^{6}5d \rightarrow 4f^{7}$ electron transition of Eu^{2+} ions are available. Therefore, the previous occasional red glow under UV is fairly covered by the resulted phosphorescent greenish glow under UV. In the case of fluorescent spectroscopy, increasing Eu and Dy concentration caused a lower intensity of fluorescence emission resulted from the excitation radiation of 254 nm due to the increased concentration of impurities in the samples because the fluorescence emission of 254 nm is actually a lattice emission. Therefore, the increased concentration of dopants reduces the emission intensity.

The particle size remained the same through the samples; however, some agglomeration takes place after the calcination process in all of the samples, as XRD and SEM analysis approved this claim. Phosphorescence radiation took place after the strontium aluminates undergo the calcination/reduction process and this property is attributed to $4f^{6}5d \rightarrow 4f^{7}$ transition of Eu²⁺ in the samples, but there is an optimum concentration for Eu as well as other dopants in the samples. Varying afterglow length and phosphorescence and fluorescence intensities approve the important role of dopants and their concentration in the luminescence properties.

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References

- N. Thompson, P. Murugaraj, C. Rix, D.E. Mainwaring, J Alloys Compd. 537 (2012) 147-153.
- R. Aroz, V. Lennikov, R. Cases, M.L. Sanjuána, Fuente G.F., E. Muñoz, J. Eur. Ceram. Soc. 32 (2012) 4363-4369.
- 3. A.H. Wako, F.B. Dejene, H.C. Swart, B. Physica. 480

(2016) 116-124.

- E. Shafia, A. Aghaei, A. Davarpanah, M. Bodaghi, M. Tahriri, H. Alavi, Trans. Ind. Ceram. Soc. 70[2] (2011) 71-77.
- M. Elsagh, M. Rajabi, E. Amin, J Mater. Sci. 25 (2014) 1612-1619.
- S. Karimkhani Zand, S. Baghshahi, M. Rajabi, J Mater. Sci. 25 (2014) 4412-4417.
- M. Marchal, P. Escribano, J.B. Carda and E. Cordoncillo, JSST, (2003) 989-992.
- S.Y. Kaya, E. Karacaoglu, B. Karasu, Ceram. Int. 38 (2012) 3701-3706.
- H. Terraschke, M. Suta, M. Adlung, S. Mammadova, N. Musayeva, R. Jabbarov, M. Nazarov, C. Wickleder, Journal of Spectroscopy, 2015 (2015).
- 10. Y. ZHU, M. GE, C. Zhi, J RARE EARTH. 31 (2013) 1043.
- Z. Ji, W. Bao, Q. Mao, J. Xi, Z. Kong, J. Zhang, Ceram. Int. 41 (2015) 11646-11650.
- T. Ishigaki, H. Mizushinab, K. Uematsub, N. Matsushitac, M. Yoshimurac, K. Todaa, M. Sato, Mater. Sci. Eng. B. 173 (2010), 109-112.
- Q. Guanming, C. Yongjie, C. Jingqiang, G. Xiujuan, W. Hui, J RARE EARTH. 25 (2007) 86-89.
- Y. Kamiyanagi, M. Kitauraa, M. Kaneyoshi, J. Lumin. 122-123 (2007) 509-511.
- T. Peng, H. Yang, X. Pu, B. Hu, Z. Jiang, C. Yan, Mater. Lett. 58 (2004) 352- 356
- 16. F. A. Miller, C. H. Wilkins, 24[8] (1952) 1253-1294.