International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 07 | July -2017 www.irjet.net p-ISSN: 2395-0072

Synthesis and Characterization of Mechanoluminescent $NaAlSiO_4$:Eu, Nd phosphor for impact sensor

T. R. Sanodiya[1], Piyush Jha[2*]

[1]Principal, Yashoda Bai Patel College, Kurai, Seoni, Madhya Pradesh, India
[2]Assistant Professor, Department of Applied Physics, Raipur Institute of Technology, Raipur, Chhattisgarh, India

---

Abstract - *Mechanoluminescent materials give a promising tool for detecting stress distribution in solids. The $NaAlSiO_4$:Eu,Nd phosphor was prepared by conventional solid state reaction method. XRD analysis shows that hexagonal nepheline structure with space group $P6_3$. The ML intensity of $NaAlSiO_4$:Eu,Nd phosphor initially increases with time, attains a peak value and decreases with time. The time corresponding to ML intensity does not change significantly with increasing impact velocity. The peak ML intensity increases linearly with square of impact velocity. The PL emission peak lies at 550 nm. This measurements made suitability of $NaAlSiO_4$:Eu,Ny phosphor for developing stress and damage sensors.*

Key Words: *Mechanoluminescence, Triboluminescence, $NaAlSiO_4$:Eu,Nd phosphor, Sensors, Photoluminescence*

1. INTRODUCTION

Light emission caused by mechanical deformation such as compression, grinding, cutting, etc., in solid materials is known as mechanoluminescence (ML) (sometimes called triboluminescence when friction occurs) [1,2]. ML has a long history [3] and has recently been applied to real-time sensors of mechanical stress [4] and structural damage [5] and a resource of X-ray [6]. Several papers have described theoretically and experimentally good aspects of ML [7-13]. Elastic and plastic deformation gives elastico-mechanoluminescence (EML) and plastico-mechanoluminescence (PML). Luminescence due to fracture is called fracto-mechanoluminescence (FML) [1,2]. For the development of damage sensors and pressure sensors, it is very essential to study FML.
Many ML materials have been developed such as ZnS:Mn, $SrAl_2O_4$:Eu, $SrAl_2O_4$:Eu, Dy, $SrAl_2O_4$:Ce, $SrAl_2O_4$:Ce,Ho $SrMgAl_6O_{11}$:Eu, $SrBaMgSi_2O_7$:Eu, $SrCaMgSi_2O_7$:Eu, $Sr_2MgSi_2O_7$:Eu, $Ca_2MgSi_2O_7$:Eu,Dy, $CaYAl_3O_7$:Eu, $(Ba,Ca)TiO_3:Pr^{3+}$, $MgGa_2O_4$:Mn, $ZnGa_2O_4$:Mn, $BaAl_2Si_2O_8$:rare earth element, $Ca_2Al_2SiO_7$:Ce, ZrO_2:Ti and ZnMnTe, ZnS:Mn, Te [3]. So far, $SrAl_2O_4$:Eu, Dy phosphors is found very intense ML material and fulfill all need of sensors but its chemical stability is poor. It is need of development to produce stable ML material for sensors. $NaAlSiO_4$:Eu,Ny phosphor is one of them.

Thus, developing of excellent ML materials in the present era for ML sensor application is still an important task. The present paper reports in detail for the first time, the characteristics of ML in $NaAlSiO_4$:Eu,Nd phosphor induced using a impulsive excitation technique.

2. EXPERIMENTAL

The $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor is prepared by conventional solid state reaction method (SSR). The used precursor materials are Na_2CO_3 (99.9%), Al_2O_3 (99.9%), SiO_2 (99.9%), MgO (99.9%), Eu_2O_3 (99.9%) and Nd_2O_3 (99.9%). These material were mixed with the addition of ethanol and ground for 2 h. Stoichiometric mixtures of raw materials were sintered in an alumina crucible at 1200 ºC in carbon reducing atmosphere for 10 h. After cooling it to room temperature naturally, the as-obtained sample was ground into powder with the help of agate mortar.
The prepared $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor was characterized by powder XRD method. PANalytical 3 kW X'pert Powder XRD - Multifunctional instrument is used for XRD pattern and the data was collected over the 2θ range 10–100° at room temperature. The photoluminescence (PL) spectrum was recorded using Carry eclipse fluorescence spectrophotometer, in which the wavelength of the light used for excitation was 365 nm. In the present investigation the ML in $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor was excited using impulsive technique reported previously [14].

3. RESULTS

For crystal structure determination, powder XRD analysis has been carried out. The typical XRD pattern

of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor is shown in Fig. 1. The position and intensity of diffraction peaks of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor are well matched with Joint Committee Powder Diffraction Standard data (JCPDS) file (PDF #35-0424),). XRD analysis revealed that prepared sample are chemically and structurally $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor. The crystal structure of the $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor was hexagonal nepheline structure with space group $P6_3$.

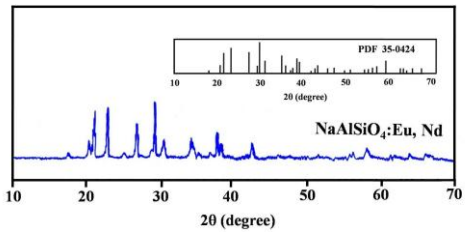

Fig.1 XRD pattern of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor.

Fig.2 shows the time dependence of the ML intensity of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor at 242 cm/sec impact velocity. It depicts from Fig.2 that when the piston makes an impact on the $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor, then initially the ML intensity increases with time and attains a peak value at a particular time, and later on it decreases with time. The local piezoelectricity of the phosphor which produces near the dopant center is responsible for ML.

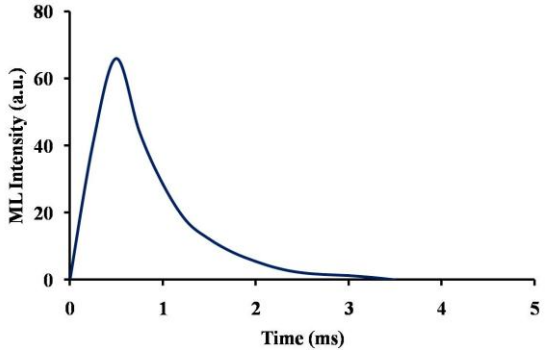

Fig.2 Time dependence of ML intensity of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor (at 242 cm/sec)

Fig.3 shows the semilog plot of I versus $(t-t_m)$ for $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor. It is found from Fig.3 that, initially the ML intensity decreases at a fast rate, and later it decreases at slow rate. The value of the slope β for fast decay and slope χ for slow decay in the semilog plot of I versus $(t-t_m)$ are shown in Table 1 for 242 cm/sec impact velocity. It is found that the fast decay time τ_f (= 1/β) and slow decay time τ_s (= 1/χ) do not change significantly with the impact velocity v_o.

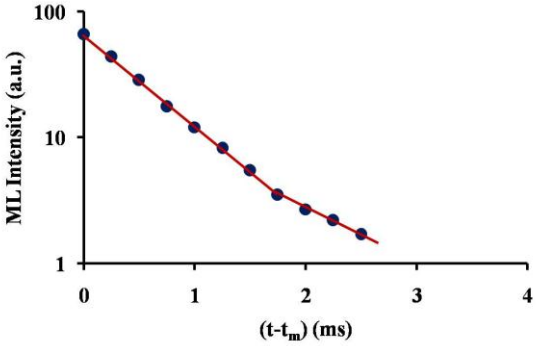

Fig.3 Semi-log plot of the ML intensity versus $(t-t_m)$ for $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor (at 242 cm/sec).

Table 1
Values of t_m, ξ, χ, τ_r, and τ_s for
$Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor

Phosphor	Impact velocity v_0(cm/s)	t_m (ms)	β (ms^{-1})	χ (ms^{-1})	$\tau_f=1/\xi$ (ms)	$\tau_s=1/\chi$ (ms)
$Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$	242	0.41	1.672	0.925	0.597	1.08

Fig.4 depicts the dependence of t_m (time corresponding to ML intensity) on impact velocity for $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor. It is seen that the value of t_m does not change significantly with increasing value of the impact velocity that mean the sample phosphors could not suppress to a certain extend.

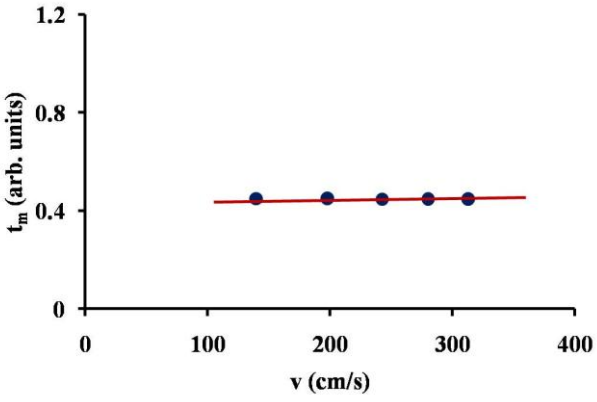

Fig.4 Dependence of t_m on impact velocity for $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor.

Fig.5 shows that the peak ML intensity increases linearly with square of increasing impact velocity. This result shows that some part of the mechanical energy

or piezoelectric energy is converted into the light energy. The Young's modulus of melilite compound $NaAlSiO_4$ reaches 103 GPa [15]. At low impact velocity (in our experiment up to 342 cm/s) using 800 g piston, the impact energy would induce an extra amount of detrapping of trapped carriers in addition to detrapping by thermal energy. At small value of initial velocity the ML intensity increases linearly with square of impact velocity [8]. It is revealed by the experiment that the strong ML of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor may be useful in designing the impact stress sensors and impact velocity sensors.

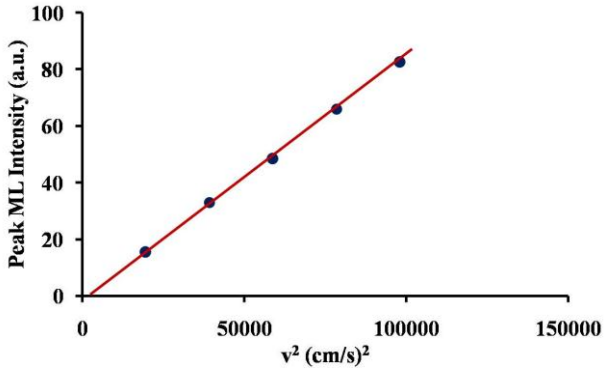

Fig.5 Dependence of the peak ML intensity on square of impact velocity of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor.

Fig.6 shows the PL emission spectra (λ_{ex} =400nm) of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor. The broad emission peak can be attributed due to 4f-5d transition of Eu^{2+} ions, which exhibits a greenish yellow emission centered at 550 nm.

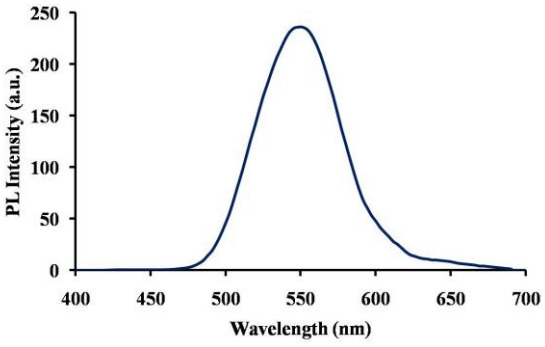

Fig.6 Photoluminescence spectra of $Na_{0.96}AlSiO_4:Eu_{0.02},Nd_{0.02}$ phosphor.

4. CONCLUSIONS

In the present study the $NaAlSiO_4$:Eu,Ndphosphor was prepared by conventional solid state reaction method. The crystal structure of $NaAlSiO_4$:Eu,Nd phosphor is determined by XRD shows hexagonal nepheline structure with space group $P6_3$. The ML intensity initially increases with time, attains a peak value and then, decreases with time. The time corresponding to the ML intensity does not change significantly with increasing impact velocity. The peak ML intensity increases linearly with square of impact velocity. The PL spectra lie at 550 nm. These measurements made suitability of $NaAlSiO_4$:Eu,Nd phosphor for developing stress and damage sensors.

References

[1] B. P. Chandra, in: D.R. Vij (Ed.), Luminescence of Solids, Plenum Press, New York, (1998).

[2] B.P. Chandra, in: Stashans A, Gonzalez S, Pinto HP (Eds.), Electronic and Catalytic Properties of Advanced Materials, Transworld Research Network, Trivandrum, Kerala, India, (2011).

[3] P. Jha and B.P. Chandra, Survey of the literature on mechanoluminescence from 1605 to 2013, Lumin. Vol. 29, pp. 977- 993, 2014.

[4] C. N. Xu, T. Watanabe, M. Akiyama and X. G. Zheng, Artificial skin to sense mechanical stress by visible light emission. Appl. Phys. Lett. Vol. 75, pp. 1236-1238, 1999.

[5] I. Sage and G. Bourhill, Triboluminescent materials for structural damage monitoring, J. Mater. Chem. Vol. 11, pp. 231–245, 2001.

[6] C.G. Camara, J.V. Escobar, J.R. Hird and S.J. Putterman, Correlation between nanosecond X-ray flashes and stick–slip friction in peeling tape, Nature Vol. 455, pp. 1089–1092, 2008.

[7] B. P. Chandra, V. K. Chandra and Piyush Jha, Modelling of fracto-mechanoluminescence damage sensor for structures, Sens. Actuators A Vol. 230, pp. 83-93, 2015,.

[8] P. Jha and B. P. Chandra, Impulsive excitation of mechanoluminescence in $SrAl_2O_4$:Eu,Dy phosphors prepared by solid state reaction technique in reduction atmosphere, J. Lumin. Vol. 143, pp. 280-287, 2013.

[9] Piyush Jha, Effect of UV irradiation on different types of luminescence of $SrAl_2O_4$:Eu, Dy phosphors, Lumin. Vol. 31, pp.1302-1305, 2016.

[10] V. K. Chandra, B.P. Chandra and P. Jha, Strong luminescence induced by elastic deformation of

piezoelectric crystals, Appl. Phys. Lett. Vol. 102, pp. 241105-1-8, 2013.

[11] V. K. Chandra, B.P. Chandra and P. Jha, Self-recovery of mechanoluminescence in ZnS:Cu and ZnS:Mn phosphors by trapping of drifting charge carriers, Appl. Phys. Lett. Vol. 103, pp. 161113-1-5, 2013.

[12] B. P. Chandra, V.K. Chandra and P. Jha, Microscopic theory of elastico-mechanoluminescent smart materials, Appl. Phys. Lett. Vol. 104, pp. 031102-031106, 2014.

[13]B. P. Chandra, V.K. Chandra and P. Jha, Piezoelectrically-induced trap-depth reduction model of elastico-mechanoluminescent materials, Physica B Vol. 461, pp.38-48, 2015.

[14] B. P. Chandra, S. Tiwari, M. Ramrakhiani and M. H. Ansari, Mechanoluminescence in centrosymmetric crystals, Cryst. Res. Technol. Vol. 26, pp. 767-81, 1991.

[15] M. Mookherjee, Mid-mantle anisotropy: Elasticity of aluminous phases in subducted MORB, Geophysical Research Letters Vol. 38, pp. L14302-1-5, 2011.

BIOGRAPHIES

T. R. Sanodiya obtained his Ph.D. in Physics, from Rani Durgavati University, Jabalpur, MP, India in the year 2011. He is a Principal of Yashoda Bai Patel College, Kurai, Seoni, Madhya Pradesh, India. His current field of interest is optoelectronic materials.

Piyush Jha obtained his M.Phil. in Physics from Rani Dur-gavati University, Jabalpur, MP, India in the year 2008 and also Ph.D. in Physics, from Rani Durgavati University, Jabalpur, MP, India in the year 2013. He is an Assistant Professor of Applied Physics, at Raipur Institute of Tech-nology, Raipur, CG, India. His current field of interest is optoelectronic materials and sensors.