Synthesis and Characterization of Mechanoluminescent 
NaAlSiO₄:Eu, Nd phosphor for impact sensor

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Abstract - Mechanoluminescent materials give a promising tool for detecting stress distribution in solids. The NaAlSiO₄:Eu,Nd phosphor was prepared by conventional solid state reaction method. XRD analysis shows that hexagonal nepheline structure with space group P6₃. The ML intensity of NaAlSiO₄: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 measurement made suitability of NaAlSiO₄:Eu,Nd phosphor for developing stress and damage sensors.

Key Words: Mechanoluminescence, Triboluminescence, NaAlSiO₄: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 elastic-mechanoluminescence (EML) and plastic-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, SrAl₂O₄:Eu, SrAl₂O₄:Eu, Dy, SrAl₂O₄:Ce, SrAl₂O₄:Ce,Ho SrMgAl₂O₄:Eu, SrBaMgSi₂O₇:Eu, SrCaMgSi₂O₇:Eu, Sr₂MgSi₂O₇:Eu, Ca₂MgSi₂O₇:Eu,Dy, CaYAl₃O₁₂:Eu, (Ba,Ca)TiO₃:Pr³⁺, MgGa₂O₄:Mn, ZnGa₂O₄:Mn, BaAl₂Si₂O₆:rar ear element, CaAl₂Si₅O₁₂:Ce, ZrO₂:Ti and ZnMnTe, ZnS:Mn, Te [3]. So far, SrAl₂O₄: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. NaAlSiO₄:Eu,Nd 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 NaAlSiO₄:Eu,Nd phosphor induced using a impulsive excitation technique.

2. EXPERIMENTAL

The Na₀.₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ phosphor is prepared by conventional solid state reaction method (SSR). The used precursor materials are Na₂CO₃ (99.9%), Al₂O₃ (99.9%), SiO₂ (99.9%), MgO (99.9%), Eu₂O₃ (99.9%) and Nd₂O₃ (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 °C 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 Na₀.₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ phosphor was excited by powder XRD method. PANalytical 3 kWX’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 Na₀.₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ 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 $\beta$ for fast decay and slope $\chi$ 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 $\tau_f (= 1/\beta)$ and slow decay time $\tau_s (= 1/\chi)$ 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>
<thead>
<tr>
<th>Phosphor</th>
<th>Impact velocity $v_o$ (cm/s)</th>
<th>t$_m$ (ms)</th>
<th>$\beta$ (ms$^{-1}$)</th>
<th>$\chi$ (ms$^{-1}$)</th>
<th>$\tau_f = 1/\beta$ (ms)</th>
<th>$\tau_s = 1/\chi$ (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$<em>{0.96}$AlSiO$<em>4$:Eu$</em>{0.02}$,Nd$</em>{0.02}$</td>
<td>242</td>
<td>0.41</td>
<td>1.672</td>
<td>0.925</td>
<td>0.597</td>
<td>1.08</td>
</tr>
</tbody>
</table>

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 NaAlSiO₄ reaches 103 GPa [15]. At low impact velocity (in our experiment up to 34.2 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 Na₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ phosphor may be useful in designing the impact stress sensors and impact velocity sensors.

The crystal structure of NaAlSiO₄:Eu,Nd phosphor is determined by XRD shows hexagonal nepheline structure with space group P6₃. 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 NaAlSiO₄:Eu,Nd phosphor for developing stress and damage sensors.

**Fig.5** Dependence of the peak ML intensity on square of impact velocity of Na₀.₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ phosphor.

**Fig.6** shows the PL emission spectra (λₑₓ = 400 nm) of Na₀.₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ phosphor. The broad emission peak can be attributed due to 4f-5d transition of Eu²⁺ ions, which exhibits a greenish yellow emission centered at 550 nm.

![Photoluminescence spectra](image)

**Fig.6** Photoluminescence spectra of Na₀.₉₆AlSiO₄:Eu₀.₀₂,Nd₀.₀₂ phosphor.

### 4. CONCLUSIONS

In the present study the NaAlSiO₄:Eu,Nd phosphor was prepared by conventional solid state reaction method.

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**References**


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BIOGRAPHIES

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