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Laser induced elastico mechano luminescence of $SrAl_2O_4$: Eu phosphor

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Abstract
When γ – irradiated elastic mechano luminescent materials $SrAl_2O_4$: Eu are exposed to 1060 nm infrared pulse of nanosecond duration from CO_2 laser, then stress produced in the crystals excites visible luminescence due to piezoelectric field in $SrAl_2O_4$: Eu phosphor because they are non – centro symmetric. In the present investigation $SrAl_2O_4$: Eu crystals are given laser shocks and ML intensity recorded. During laser induced shocks, ML intensity increases linearly with stress and attains a peak value at a particular time and then decays exponentially with time. A theoretical approach has been proposed to explain the experimental results.

Keywords: Elastico ML, phosphor, infrared laser.

INTRODUCTION

Machanoluminescence (ML) can be excited by impulsive deformation of solids [1]. The ML can be excited by the shock – waves produced during exposure of the materials to laser pulses [5]. When crystals are cleaved by laser, light emission takes place known as mechanoluminescence (ML) [1-4]. On cleavage of crystals, charged surfaces are produced which may cause dielectric breakdown of the solids and the intervening gases. Thus, light emission may take place. In the case of $SrAl_2O_4$:Eu crystals, the ML measurements after high purification has not been made, but it has been found that for lower concentration of Eu^{2+} ions in $SrAl_2O_4$, the ML intensity increases drastically with increasing concentration of Eu^{2+}.

THEORY

In the measurement of the elastico ML of $SrAl_2O_4$ phosphors, EML is induced by laser light for pressing the samples. If Ω is the activation volume,n_1 is the number of effective defect centres in a crystal, n_c is the number of crystallites in the sample, and n_t is the concentration of filled electron traps, then the total number of detrapable traps is $n_{t_0}=\Omega n_1 n_t n'_c$ If d_0 is the local piezoelectric constant near the effective defect centres, then for the applied pressure p, the piezoelectric charge q near the effective defect centres is given by, q = d_0p. If the crystal is compressed at a fixed pressing rate $\dot{p}$ or strain rate έ, then in the elastic region, q is given by

$$q = d_0 p = d_0 \dot{p} t = d_0 Y \dot{\varepsilon} t \qquad .....(1)$$

where Y is the Young's modulus of the elasticity of the crystal. If f_c is the characteristic piezoelectric field then we can write the following equation

$$-\frac{dn_t}{df} = \frac{n_t}{f_c} - zn_t \qquad .....(2)$$

where f is the piezoelectric field near Eu^{2+} ions, n_t is the number of filled electron traps at any time t, and z = 1/f_c.

Integrating Eq. (2) and taking n_t=n_{to} for the threshold field f=f_{th} we get

$$n_t = n_{t_0} \exp\left[-z(f - f_{th})\right] \qquad .....(3)$$

Where n_{to} is the total number of the filled electron traps in the activation volume Ωn_l.

Using Eq. (3), the total number of detrapped electrons can be expressed as

$$n_d = \left(n_{t_0} - n_t\right) = n_{t_0}[1 - \exp\{-z(f - f_{th})\}] \qquad ....(4)$$

In the elastic region, z(f-f_{th}) is much less than 1, hence, Eq. (4) can be written as

$$n_d = n_{t_0}[1 - 1 + z(f - f_{th})] = n_{t_0} z(f - f_{th}) \qquad .....(5)$$

Now, differentiating Eq. (5), we get

$$\frac{dn_d}{dt} = n_{t_0} z \frac{df}{dt} \qquad .....(6)$$

As the rate of generation g of electrons in the conduction band will be equal to the rate of detrapping of electrons, we can write

$$g = n_{t_0} z \frac{df}{dt} \qquad .....(7)$$

If τ is the lifetime of electrons in the conduction band, then the change in the number of electrons in the conduction band can be expressed as

$$\Delta n = g\tau = n_{t_0} z \frac{df}{dt} \tau \qquad .....(8)$$

Using Eq. (8), the current density j flowing in the crystal can be written as

$$j = \Delta n q v_d \qquad .....(9)$$

where q is the electronic charge and V_d is the drift velocity.

If μ is the mobility of electrons in the crystals, then $V_{d}= \mu f$, and Eq. (9) can be expressed as

$$j = \Delta n q \mu f \qquad \ldots..(10)$$

Thus, the rate r for the flow of electrons in the conduction band in the crystal is given by

$$r = \frac{j}{q} = \Delta n v_d = \Delta n \mu f \qquad \ldots..(11)$$

From Eqs. (8) and (11), we get

$$r = \Delta n v_d = n_{t_0} z \tau \mu f \frac{df}{dt} \qquad \ldots..(12)$$

If σ is the capture-cross section of the energy state for the excited Eu^{2+} ions, and n_c is the concentration of Eu^{2+} centres, the rate of generation of excited Eu^{2+} ions can be expressed as

$$R = \sigma n_c \Delta n v_d = \sigma n_c n_{t_0} z \tau \mu f \frac{df}{dt} \qquad \ldots..(13)$$

If η is the efficiency for the radiative decay of excited Eu^{2+} ions, then the ML intensity can be expressed as

$$I = \eta R = \eta \sigma n_c n_{t_0} z \tau \mu (f - f_{th}) \frac{df}{dt}$$

or,

$$I = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu (f - f_{th}) \frac{df}{dt} \qquad \ldots..(14)$$

Where f_{th} is the threshold piezoelectric field for the ML emission.

It is to be noted that n_c is related with n_1, hence, there should be nonlinear relation between I and n_c. A nonlinear relation between I and n_c has been observed. If b is the co-relating factor between the piezoelectric field f and the piezoelectric charge q, then, f = bq, and Eq. (14) can be written as

$$I = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu b^2 (q - q_{th}) \frac{dq}{dt} \qquad \ldots..(15)$$

where $f_{th}= b\, q_{th}$

Now, we will consider the EML Under Increasing Stress and Fixed Stress Condition- Case I – Rise of EML intensity. From Eqs. (1) and (15), we get

$$I = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu b^2 d_0^2 (p - p_{th}) \frac{dp}{dt} \qquad \ldots...(16)$$

In terms of strain rate, Eq. (16) can be expressed as

$$I = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu b^2 d_0^2 Y \dot{\varepsilon} (p - p_{th}) \qquad \ldots..(17)$$

Equation (17) indicates that for a given strain rate the EML intensity should increase linearly with the pressure, and for a given pressure, the EML intensity should increase linearly with the strain rate.

Case – II Decay of EML intensity

When the laser impulse has been stopped then decay of EML is related to the decrease of the strain rate of the sample with time. If τ_m is the time-constant then the decrease of strain rate with time can be expressed as

$$\dot{\varepsilon} = \dot{\varepsilon}_0 \exp\left[-\frac{(t-t_m)}{t_m}\right] = \dot{\varepsilon}_0 \exp[-\phi(t-t_m)] \qquad \ldots..(18)$$

where $\phi = 1/T_m$, t_m is the time at which the laser pulse has been turned off and $\dot{\varepsilon}_0$ is the strain rate at $t= t_m$.

Using Eq. (18), the change of pressure dp in time dt can be expressed as

$$dp = \dot{p} dt = Y \dot{\varepsilon} dt = Y \dot{\varepsilon}_0 \exp[-\phi(t-t_m)] dt \qquad \ldots..(19)$$

Integrating Eq. (19) and taking $p = p_m$, at $t = t_m$, we get

$$p = p_m + \frac{Y \dot{\varepsilon}_0}{\phi} [1 - \exp\{-\phi(t-t_m)\}] \qquad \ldots..(20)$$

Thus, in this case $q = d_0 p$ and $dq/dt = d_0\, dp/dt$, can be expressed as

$$q = d_0 p_m + \frac{d_0 Y \dot{\varepsilon}_0}{\phi} [1 - \exp\{-\phi(t-t_m)\}] \qquad \ldots..(21)$$

and,

$$\frac{dq}{dt} = d_0 Y \dot{\varepsilon}_0 [\exp\{-\phi(t-t_m)\}] \qquad \ldots..(22)$$

Using Eqs. (15), (21) and (22), the EML intensity for $q >> q_{th}$, can be written as

$$I = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu b^2 \left[\left[d_0 p_m + \frac{d_0 Y \dot{\varepsilon}_0}{\phi}\right][1 - \exp\{-\phi(t-t_m)\}] d_0 Y \dot{\varepsilon}_0 [\exp\{-\phi(t-t_m)\}]\right] \ldots..(23)$$

As φ is a very large, $d_0 p_m \gg \frac{d_0 Y \dot{\varepsilon}_0}{\phi}$, and Eq. (23) can be written as

$$I = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu b^2 d_0^2 p_m Y \dot{\varepsilon}_0 \exp[-\phi(t-t_m)]$$

or,

$$I = I_m \exp[-\phi(t-t_m)] \qquad \ldots..(24)$$

where $I_m = \eta \sigma \Omega n_1 n'_c n_t n_c z \tau \mu b^2 d_0^2 p_m Y \dot{\varepsilon}_0$ is the EML intensity at $t=t_m$.

EXPERIMENTAL SUPPORT TO THEORY

Fig.1 shows the mechanoluminescence glow curve induced by the application of laser impulse on $SrAl_2O_4$:Eu, phosphor (Akiyama et al.2002) . It is seen that, initially the EML intensity increases linearly with time, attains peak value I_m for a particular time t_m. These results are in accordance with Eqs. (17), and (24).

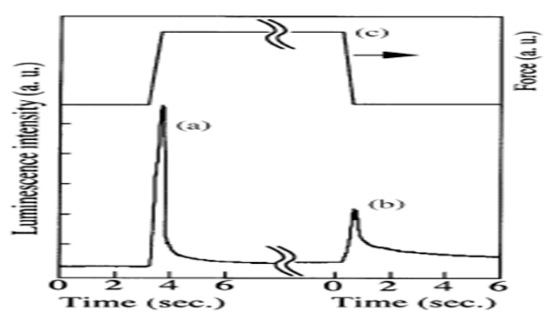

Fig 1. Mechanoluminescence glow curve of $SrAl_2O_4$:Eu, produced during (a) the application of laser impulse and (b) the removal of laser impulse

CONCLUSION

The EML intensity of $SrAl_2O_4$:Eu phosphor excited by laser impulse, initially intensity increases with time, attains a peak value and later on it decreases with time, in which the decay of EML intensity gives the decay time of impact stress and the slow decay time of the EML intensity gives the lifetime of elections in the shallow traps lying in the normal piezoelectric region of the crystals.

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