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Pulse – Induced Mechanoluminescence of γ-Irradiated KBr Crystals

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Abstract

The mechanoluminescence (ML) intensity of KBr crystal increases linearly with the γ- doses. This fact indicates that the ML has potential for the radiation dosimetry. In fact, during the fracture of γ-irradiated KBr crystals moving dislocation capture electrons from the F- centres and the recombination of dislocation captured electrons with hole centres gives rise to the light emission. When the γ-irradiated KBr crystals are deformed by the impact of a low power electrical hammer, initially the ML intensity increases with time, attains a maximum value and then it decreases with time. The time t_m does not change significantly with increasing value of the impact velocity. Whereas, in the case of impulsive excitation of ML, the fast and slow components of the ML decay are observed, in the case of the ML excitation by low power electric hammer only the fast decay component is observed and the slow component of the ML decay could not be observed.

Keywords : Mechanoluminescence, Triboluminescence, Coloured alkali halide, Fracture.

1. INTRODUCTION

The elementary processes occurring in the solid state mechanoluminescence (ML) of crystals are the generation, transport and recombination of free charge carriers caused by the deformation and fracture of crystals, followed by the light emission during excitation of luminescence centres or electron-hole radiative recombination. The time response of ML is determined by the superposition of these processes which are usually difficult to disentangle. One way to understand such complications is the measurement of the transient ML induced by the pressure pulses of short duration. Molotskii and Shmurak [1] have studied the pressure pulse-induced elastico ML and plastico ML of γ-irradiated alkali halide crystals. Shrivastava [2], and Chandra and Ramrakhiani [3] have reported two ML peaks in the ML versus time curve of γ-irradiated alkali halide crystals induced by the impact of a moving piston onto the crystals. The ML of II-VI semiconductors has also been studied at fast strain rate by applying pressure pulses of short duration[4,5]. Warschauer and Reynolds [6] have repoted very interesting results on the pulse-induced ML of cadmium sulphide crystals. Alzetta et al. [7] have reported that when top-hat compression pulse is applied to the Mn-doped ZnS powder suspended in oil in a pressure cell, then a burst of light was emitted at both the instances of rise and fall of the compressional pulse. Meyer et al. [8, 9] have made detailed investigation on the pressure dependence of the ML and voltage dependence of EL. The ML in luminescent ZnS powder has been studied by Sodomka [10] for different pressures. It was found experimentally that the ML appears only when there is a time change in the applied pressure. Similar experiments were carried out by Chudacek and Sodomka [11] in Cu doped ZnS. Impact velocity and temperature. studies of shock-induced luminescence from X-cut quartz and Z-cut lithium niobate have shown that the process of luminescence is closely associated with dynamic yielding [12,13]

The present paper reports the fracto ML of γ-irradiated alkali halide crystals induced by the application of pressure-pulses of short duration and makes a comparison between the experimental and theoretical result, in which a good agreement is found.

2. EXPERIMENTAL

The single crystals of KBr were grown from the slow cooling of their melt. For producing the colour centres, KBr crystals were exposed to γ-ray using ^{60}Co source. in which the dose rate was 0.59 kGray/hour. For different doses, the crystals were irradiated for different time intervals. The pulse induced ML was excited by low power electrical hammer. The velocity of impact is measured by using a velocity transducer. The crystal size taken in the present experiment was 1x1x1mm^3.

3. RESULTS AND DISCUSSION

Figs.1 shows the time dependence of the ML intensity of γ-irradiated KBr crystals for different impact velocities of the electric hammer. It is seen that, initially the ML intensity increases with time, attains a peak value I_m at a particular time t_m, and later on it

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decreases with time and finally disappears. It is to be noted that, whereas two peaks appear in the fracto ML of γ-irradiated alkali halide crystals when they are deformed impulsively, in the fracto ML induced by the deformation caused by impact of an electrical hammer only one peak appears in ML intensity versus time curve. It is seen that, whereas, the peak ML intensity I_m increases with the impact velocity of the piston, there is no significant changes in the value of t_m with increasing impact velocity.

Fig.2 illustrates the semilog plot of I versus ($t-t_m$) for different impact velocities for γ-irradiated KBr crystals. It is seen that the slope of the semilog plot of I versus ($t-t_m$) does not change significantly with increasing impact velocity of the electric hammer. The value of slopes for different impact velocities for γ-irradiated KBr, crystal is 0.87 sec^{-1} and decay time is 1.17 sec.

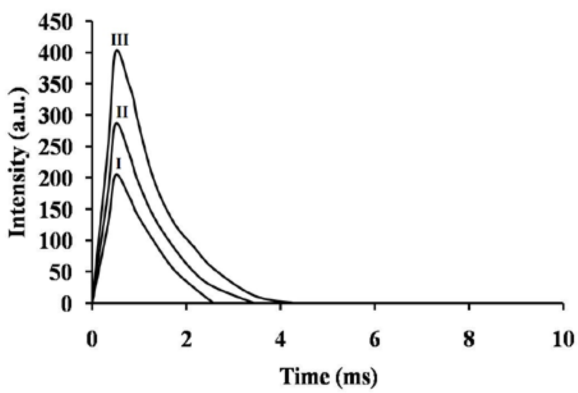

Fig.1: Time dependence of the ML intensity of KBr crystals (Curves I, II and III correspond to the impact velocity 57, 95, 152 cm/sec, respectively).

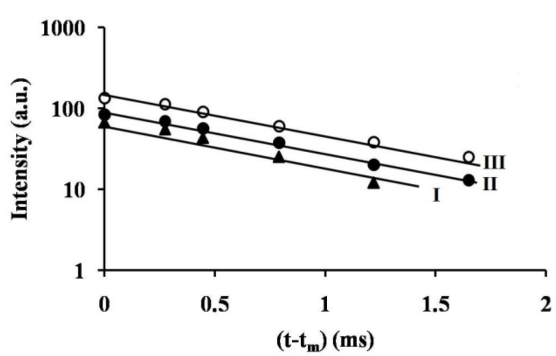

Fig.2 : Semilog plot of ML intensity versus ($t-t_m$) for KBr crystals (Curves I, II and III correspond to the impact velocity 57, 95, 152 cm/sec, respectively).

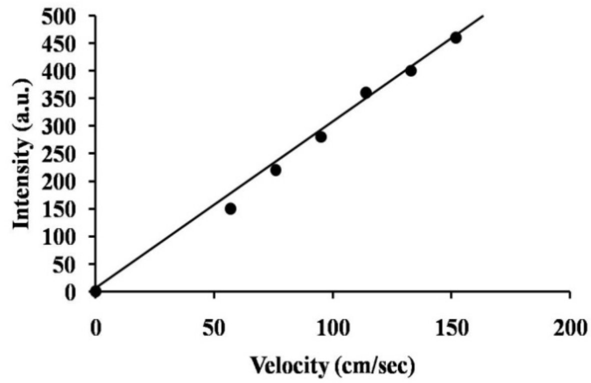

Fig.3: Impact velocity dependence of the ML intensity of γ-irradiated KBr crystals.

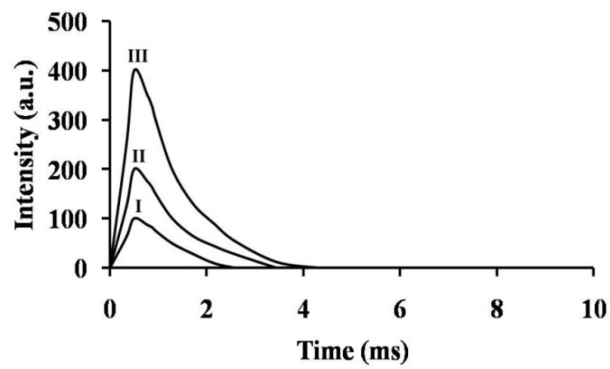

Fig.4:Time dependence of the ML intensity of KBr crystals for different γ – doses given to the crystals (Curves I, II and III correspond to 0.147, 0.295 and 0.59 k Gray/ hour).

Fig.3 shows the impact velocity dependence of the fracto ML of γ-irradiated KBr crystals. It is seen that the ML intensity of the crystals increases linearly with the impact velocity.

Figs.4 illustrates that ML intensity versus time curves for different γ- doses given to KBr crystals, in which the impact velocity was kept constant. It is seen that the ML intensity increases linearly with the γ doses given to the crystals. The ML intensity of γ-irradiated KBr crystals also increases with increasing size of the crystals.

4. THEORY

In the experiment for the measurement of fracto ML induced by impulsive deformation, a moving piston makes an impact on to a crystal and the ML is produced during fracture of the crystal. If v_0 is the initial velocity of the piston at impact, then the initial compression rate of the sample is given by, dx/dt = v_0. If τ_r is the time-constant for the relaxation of the moving piston, then we can write the following equation

$$\frac{dx}{dt} = v_0 \exp\left(-\frac{t}{\tau_r}\right) = v_0 \exp(-\xi t) \qquad \ldots (1)$$

where x is the compression and $\xi = 1/\tau_r$, is the rate-constant for the relaxation of moving piston.

Integration of Eq. (1) gives

$$x = -\frac{v_0}{\xi}\exp(-\xi t) + c \qquad \ldots (2)$$

where C is the constant of integration.

Taking x = 0, at t = 0, we get, $c = v_0/\xi$. Thus, Eq. (2) can be expressed as

$$x = \frac{v_0}{\xi}[1 - \exp(-\xi t)] \qquad \ldots(3)$$

If H is the thickness of the crystal, then the strain ε can be expressed as

$$\varepsilon = \frac{x}{H} = \frac{v_0}{H\xi}[1 - \exp(-\xi t)] \qquad \ldots(4)$$

Expressions for the rise of ML intensity I_r, time for peak ML intensity t_m, peak ML intensity I_{m1}, total ML intensity I_T, decay of ML intensity I_d and slow decay of ML intensity I_{ds} can be expressed as

$$I_r = \frac{2\eta\beta\lambda r_F n_F D b Z_0 V K_0 v_0 \alpha_1}{H\alpha} t \qquad \ldots(5)$$

$$t_{m1} = \frac{1}{(\beta-\xi)}\ln\left(\frac{\beta}{\xi}\right) \qquad \ldots(6)$$

$$I_{m1} = \frac{2\eta\lambda n_F r_F D b Z_0 V K_0 v_0 \alpha_1}{H\alpha} = \frac{2\eta\lambda n_F r_F D b Z_0 V K_0 v_0 p_F}{H} \qquad \ldots(7)$$

$$I_d = I_m \exp[-\xi(t - t_m)] \qquad \ldots(8)$$

and,

$$I_{T1} = 2\eta\lambda r_F n_F D b Z_0 V K_0 p_F [1 - \exp(-\delta v_0)] \qquad \ldots(9)$$

5. CONCLUSION

In fact, during the fracture of γ-irradiated KBr crystals moving dislocation capture electrons from the F-centres and the recombination of dislocation capture electron with hole centre give rise to the light emission. When the KBr crystals are deformed by the impact of a low power electrical hammer, initially the ML intensity increases with time, attains a maximum value and then it decreases with time. The time t_m does not change significantly with increasing value of the impact velocity. Whereas, in the case of impulsive excitation of ML, the fast and slow component of the ML decay are observed, in the case of the ML excitation by low power electric hammer only the fast decay component is observed. The ML intensity of KBr crystal increases linearly with the γ- doses. This fact indicates that the ML has potential for the radiation dosimetry.

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