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Mechanoluminescence Produced During Impulsive Deformation Studies of Gamma Irradiated NaBr Single Crystals

U. S. Patle*

Department of Physics,
Govt. Narmada Postgraduate College,
Hoshangabad, M.P., India.

Abstract

When a γ -irradiated NaBr crystal is deformed impulsive by impact of moving piston, then two peaks of intensities I_{m1} and I_{m2} appear in the Mechanoluminescence (ML) intensity versus time curve at times t_{m1} and t_{m2} respectively. The ML intensity after I_{m1} decays exponentially upto the minima in between I_{m1} and I_{m2} where the decay time give the relaxation time of the piston. The ML intensity after t_{m2} also decays exponentially, where the decay time give the lifetime of electrons in the dislocation band.

Keywords: impulsive deformation, Mechanoluminescence, γ – irradiation

I. INTRODUCTION

Mechanoluminescence (ML) is a type of luminescence induced by any mechanical action on solids. Only a limited number of solids exhibit ML during their elastic and plastic deformations. The term of mechanoluminescence has been used to describe whole variety of process in which light is emitted due to mechanical deformation of solid. The ML intensity of coloured alkali halide crystals, $CaSO_4$: Dy and other phosphor have been reported [1-7]. The phenomenon of non-incandescent light generation by pressing of mechanical deformation of solids is known as mechanoluminescence (ML). ML links mechanical, spectroscopic, electrical, structural and other properties of solids. A large number of organic and in organic solids exhibits the phenomenon of ML. ML can be excited either by grinding rubbing, cutting, cleaving, compressing of by impulsive deformation of solids [8-12]. It can also be excited by the thermal shocks produced during sudden cooling or heating of the solids. Primarily ML can be classified into two types: deformation ML and tribo ML. Deformation ML is produced during the deformation of solids and tribo ML is produced during the rubbing of two materials of during the separation of two materials in contact. On the basis of the deformation in solids needed for producing ML, deformation ML can further be subdivided into three types namely, elastic ML, plastic ML and fracto ML. the ML occurring during elastic deformation of solids is called elastico ML, the ML occurring during plastic deformation of solids is called plastico ML, and the ML occurring during fracture of solids is called fracto ML. It is known that coloured alkali halide crystals exhibit intense ML during their elastic and plastic deformation as well as during their fracture.

The phenomenon of mechanoluminescence (ML), i.e. the light emission produced during deformation of solids, was reported in coloured alkali halide crystals for the first time in 1930 by Urbach and Akad [13]. The linear dependence of light emission on the strain rate in X- irradiated KBr, NaCl and LiF crystals was reported by Metz et al. and Alzetta et al. [14, 15]. Several workers have reported the dislocation movement to be responsible for the ML excitation in coloured alkali halide crystals [16]. Chandra and Elyas [17] have reported that the ML is produced in coloured alkali halide crystals during the application of pressure as well as during the release of applied pressure. The present paper reports the ML of irradiated NaBr crystals produced during their impulsive deformation caused by the impact of a moving crystal onto the crystals.

II. EXPERIMENTAL

For the present investigation single crystals of NaBr were grown ising the Bridgmann technique. By cleaving a large crystal, specimens of dimension 2x2x1 mm^3 were obtained. Then they were annealed at 450^0C for four hours and exposed to ^{60}Co source. The ML was excited impulsively by dropping a load of fixed mass from different heights onto the crystals placed on a transparent Lucite plate following the method described previously [18]. In this method, the ML intensity was measured by using an RCA931A photomultiplier tube whose output was connected to a storage oscilloscope. The velocity of piston was measured by using a velocity transducer.

III. RESULTS

Fig1 shows that when a piston is dropped onto a gamma – irradiated NaBr crystal, initially the ML intensity increases with time, attains a peak value I_{m1}, at a particular time t_{m1}, then it decreases and attains a second peak value I_{m2} at a particular time t_{m2} and then it again decreases with time. It is seen from fig.1 that I_{m1}, I_{m2}, t_{m1} and t_{m2} depend upon the impact velocity, v_0 of the piston used to deform the crystals. The ML in gamma irradiated crystals appears in the deformation as well as in the

* *Correspondence Author:* ***U. S. Patle,*** *M.Sc. Ph. D.,*
Barkatullah University, Bhopal, Email: uspatle@rediffmail.com

post-deformation regions. Fig.2 (a) and 2(b) shows the plot of log (I_1) versus ($t-t_{m1}$) and log(I_2) versus ($t - t_{m2}$), respectively for NaBr crystals. These figures illustrate that the decay of I_1 and I_2 follows the relation:

$$I_1 = I_{m1} \exp[-\frac{(t-t_{m2})}{\tau_r}] \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$I_2 = I_{m2} \exp[-\frac{(t-t_{m2})}{\tau}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where I_1 is the transient ML intensity beyond t_{m1} and minima of the ML intensity versus time curve and I_2 is the transient ML intensity beyond t_{m2}. Here τ_r is the relaxation time of the piston after impact and τ is the lifetime of electrons in the dislocation band. The value of the pinning time of dislocations $\tau_p = \frac{1}{\alpha}$, can be determined from the relation

$$t_{m1} = \frac{1}{(\alpha - \delta)} \ln\left(\frac{\alpha}{\delta}\right) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where $\delta = \frac{1}{\tau_r}$. The value of τ is found to be 0.60 ms and the value of τ_r is found to be 1.65, 1.23,0.98 and 0.82 ms for the impact velocity of 140, 198, 242 and 280 cm s^{-1}, respectively. The value of τ_p (= $\frac{1}{\alpha}$) is found to be 198, 195, 210 and 215 ms for the impact velocity of 140, 198, 242 and 280 cm s^{-1}, respectively.

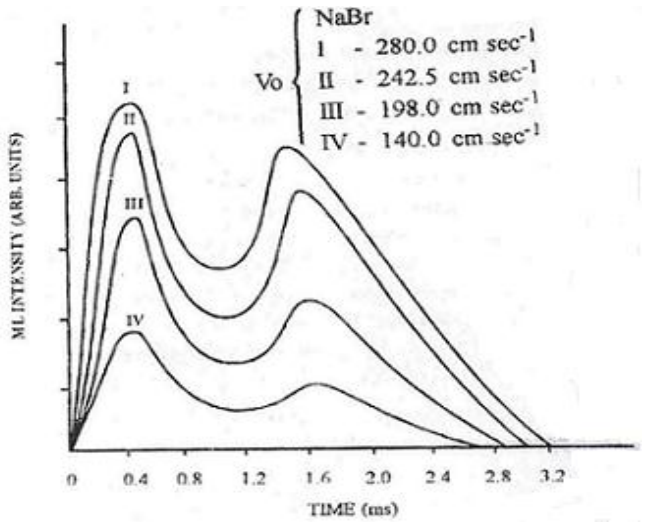

Fig. 1. Time dependence of the ML intensity of γ – irradiated NaBr crystal for different impact velocities (γ - dose = 2900 Gy, crystal size =2x2x2mm^3)

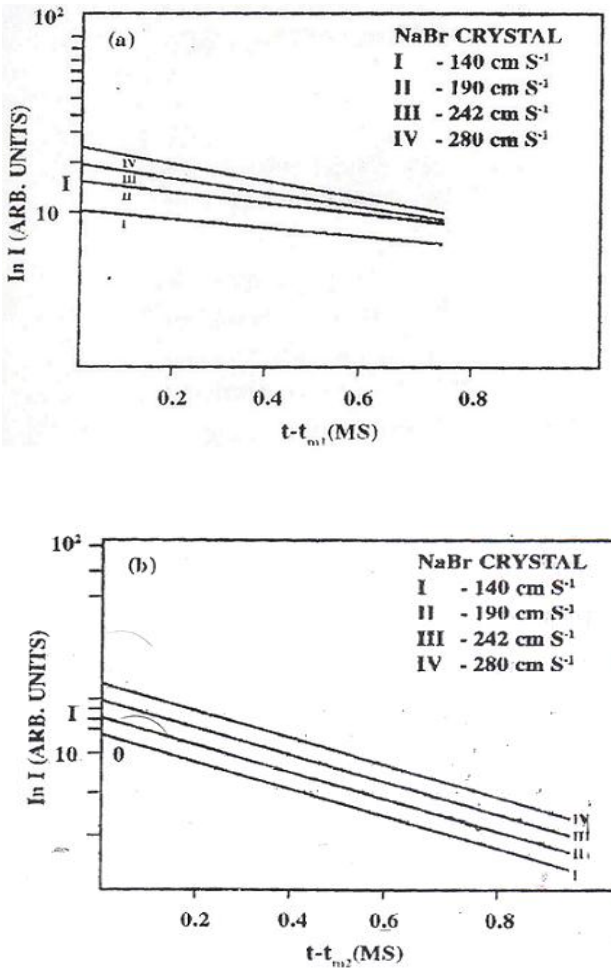

Fig. 2 (a) Plot of ln I Vs ($t-t_{m1}$) and **(b)** Plot of ln I Vs ($t-t_{m2}$) for NaBr crystals (γ - dose =2900 Gy, crystal size =2x2x1mm)

It can be shown that I_{m1} increases linearly with the impact velocity v_0, however, I_{m2} and the total ML intensity I_T (defined as the area between the ML intensity versus time curve), initially increases and then they tend to attain saturation values for higher values of the impact velocity v_0, and both t_{m1} and t_{m2} decrease with increasing value of the impact velocity of the piston.

IV. DISCUSSION

During elastic deformation the dislocations only bend between pinning points. When the stress exceeds the yield point, the dislocations break way from these points and move along the crystals. The mobile dislocations capture of trap electrons from F-centers to the states of dislocation bands and transport them to hole centre. The recombination of dislocation electrons with the holes localized in the activator centers leads to the appearance of ML, whose peak position may coincide with that of the impurity centers [19, 20]. In this model, the activation energy of ML is determined by the energy required for the excitation of the F-center electron in to dislocation states. This activation energy is of the order of 0.1 eV for coloured alkali halide crystals [20].

After the separation of the electron from the F-centres, it moves together with the dislocation and at the same time it is capable to shift along the dislocation line. Steps kinks and impurities present on the dislocation line limit the electron motion along the dislocation. Therefore the electron motion along the dislocation for a distance larger than the average distance between the defects along the dislocation axis may be considered as one-dimensional diffusion of a dislocation polaron. The effective velocity of the electron along the dislocation axis in the crystals investigated is ~ 0.1 cm/s [21]. The complicated motion of the dislocation electrons permits one to explain the quick slow components of ML illustrated in fig. 1. At high velocities of the dislocations $v_d >> v_e$ (v_e is the electron velocity along the dislocation axis), the ML kinetics is determined by the recombination of dislocation electrons with the hole centers met on the way of a moving dislocation. At small dislocation velocities $v_d << V_e$, the luminescence kinetics is conditioned by the slowly drifting dislocation electron in the attractive field of a hole localized in the luminescence centre. The decay time of ML beyond t_{m2}, realized in the post-deformation region, is the time in which a dislocation electron drift to the hole centre. The radius of interaction of a dislocation electron with holes is of the order of the Burgers vector b. The electrons move freely along the axis of dislocation between charged steps [10]. If 1 is the mean distance between steps, then the recombination cross-section is σ_r = 2b1. Thus the rate of recombination of dislocation electrons with holes is given by $R = 2\ b\ 1\ v_d\ N_r$, where v_d is the average velocity of electrons captured by dislocations, and N_r is the concentration of recombination centers. In the ML measurements the decay of ML intensity after the deformation is intersecting. In the post-deformation region, the velocity of dislocation becomes neglible, however, the dislocation electrons move along the dislocation axis at lengths bounded by charged jogs. Therefore, the rate of recombination of dislocation electrons in post-deformation region is given by $R_p = 2\ b\ v_e\ N_r$, where v_e is the average velocity of the electrons along a dislocation axis. Thus, the decay time of ML after t_{m2} may be given by

$$\tau = \frac{1}{R_p} = \frac{1}{2blv_eN_r} \quad \text{.....(4)}$$

In the case of impulsive deformation, the t_{m1} is the time at which the rate if deformation if the crystal is maximum of in other words the time at which the piston attains a maximum velocity due to the acceleration and deacceleration. In the case of impulsive deformation, t_{m2} should be equal to the time at which the rate of generation of dislocation electrons produced by the deaccelerated piston becomes equal to the rate of recombination of the dislocation electrons moving along the dislocation axis. Conclusively, it can be said that the ML provides a new technique for determining the pinning time of dislocations, the lifetime of electrons in the dislocation band and relaxation time of the piston after impact.

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