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Infrared Laser – Induced Visible Fracto Mechanoluminescence from Organic Crystals

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Abstract

The present paper reports the infrared laser – induced visible fracto mechanoluminescence (FML) from organic crystals. Laser pulse – induced shock waves as a source of mechanical stress can be used to stimulate FML. Due to the fracture caused by laser-induced shock wave, new surfaces are created in the crystal, in which the rate of creation of new surfaces is directly proportional to the exerted pressure which depends on laser fluence. Thus, the intensity of FML can be controlled by varying laser fluence. On the basis of the rate of creation of new surfaces by laser-induced shock wave, expressions are derived for the general kinetics of FML intensity, rise of FML intensity, time corresponding to the FML intensity versus time curve, peak FML intensity, total FML intensity and decay of FML intensity, in which a good agreement is found between the theoretical and experimental results.

Keywords: *Infrared laser; Fracto-mechanoluminescence; Organic crystals; Laser fluence.*

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1. INTRODUCTION

Mechanoluminescence (ML) is a type of luminescence induced by any mechanical action on solids. The cold light emissions induced by elastic deformation, plastic deformation, and fracture of solids are called elastico ML (EML), plastico ML (EML), and fracto ML (FML), respectively [1,2]. In terms of simplicity of measurement, it is highly desirable to use a new technique for excitation of ML. Attempts have been made by researchers to check the affordable feasibility of laser - induced shock wave as a source of mechanical energy which can stimulate light emission by fracture of materials [3-6]. As the semitransparent organic crystals are intense photoluminescent, direct irradiation of laser pulses on them is not applicable for the excitation of FML Therefore, an indirect but semiquantative method in which laser – induced shock wave can be used for the FML excitation [5]. This method may solve the crucial problem of generation and detection timings of FML from organic crystals which is not efficiently possible by manual rubbing and other techniques. This technique also provides facility to apply stress energy quite rapidly. This paper reports the infrared laser – induced visible fracto mechanoluminescence (FML) from organic crystals and makes a comparison between experimental and theoretical results.

2. MECHANISM OF THE FRACTO MECHANOLUMINESCENCE OF ORGANIC CRYSTALS

It has been reported that the FML in organic molecular crystals arises due to their piezoelectrification [7]. When a stress is applied on to a piezoelectric crystal, one of its surfaces is positively charged and the opposite surface is negatively charged. Due to the movement of a crack in the crystal, new surfaces are created, in which the newly created surface nearer to the positively charged surface of the crystal is negatively charged and the newly created surface nearer to the negatively charged surface is positively charged. Thus, an intense electric field of the order of $10^7 – 10^8$ Volt m^{-1} may be produced between the newly created surfaces of the crystal. This field may cause the dielectric breakdown of the crystals and the recombination of free charge carriers may give rise to the recombination luminescence. Furthermore, the accelerated electrons moving from negatively charged surface towards the positively charged surface may excite cathodoluminescence. The electric field may also cause the dielectric breakdown of intervening gases and subsequently the gas discharge FML may be observed.

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3. THEORETICAL APPROACH TO THE FRACTO ML OF ORGANIC CRYSTALS

When an organic crystal is irradiated with a laser beam of certain fluence F (energy per unit area), all the absorbed energy goes in doing work and consequently due to the laser fluence induced stress fracture of crystal takes place.

Due to the movement of a crack in the crystal, new surfaces are created. Thus, creation of new surface S due to fracture of a crystal depends on the incident laser fluence and can be expressed as

$$S = CF \tag{1}$$

where C is the proportionality constant.

If τ_r is the rise time of laser fluence, then rise of laser fluence can be written as

$$F = F_m[1-\exp(\xi t)] \tag{2}$$

where $\xi = 1/\tau_r$ is the rate-constant of laser pulse and F_m the maximum value of laser fluence.

Now using Eqs. (1) and (2), we get

$$S = CF_m[1-\exp(\xi t)] \tag{3}$$

Differentiating Eq. (3), we get

$$\frac{dS}{dt} = CF_m \exp(-\xi t) \tag{4}$$

If ρ is the surface charge density produced due to the piezoelectrification of crystal, then the rate of generation of surface charges of the newly created surfaces can be expressed as

$$G_q = \rho\frac{dS}{dt} = \rho CF_m \exp(-\xi t) \tag{5}$$

If τ_q is the time constant for the relaxation of surface charges, then the rate of change of surface charges is given by

$$\frac{dQ}{dt} = \rho CF_m \exp(-\xi t) - \beta_q Q \tag{6}$$

where $\beta_q = 1/\tau_q$, and Q is the surface charges at any time t.

Integrating Eq. (6) and taking Q=0, at t=0, we get

$$Q = \frac{\rho CF_m}{(\beta_q - \alpha)}[\exp(-\xi t) - \exp(-\beta_q t)] \tag{7}$$

Thus, the rate of relaxation R of surface charge is given by

$$R = \beta_q Q = \frac{\beta_q \rho CF_m}{H(\beta_q - \xi)}[\exp(-\xi t) - \exp(-\beta_q t)] \tag{8}$$

If η is the FML efficiency for relaxation of surface charges, then the time dependence of FML intensity can be expressed as

$$I = \eta R = \frac{\eta\beta_q \rho CF_m}{H(\beta_q - \xi)}[\exp(-\xi t) - \exp(-\beta_q t)] \tag{9}$$

Using Eq. (9), the rise of FML intensity I_r, the time t_m corresponding to the FML intensity versus time curve, intensity I_m corresponding to the peak of FML intensity versus time curve, total FML intensity I_T and the decay of FML intensity can be expressed as

$$I_r = \eta\beta_q \rho CF_m t \tag{10}$$

$$t_m = \frac{1}{(\beta_q - \xi)}\ln\left(\frac{\beta_q}{\xi}\right) \tag{11}$$

$$I_m = \eta\rho CF_m \tag{12}$$

$$I_T = \frac{\eta_0 \rho CF_m}{\xi} \tag{13}$$

$$I_d = I'_m \exp[-\xi(t - t_m)] \tag{14}$$

where I'_m *is the* extrapolated value of I_m.

4. EXPERIMENTAL SUPPORT TO THE PROPOSED THEORY

Tsuboi et al. [5] prepared a sample cell of N-Isopropylcarbazole (NIPCz) crystals whose reverse side was coated with a black pigment, which was used as a shock-generating layer. When the shock-generating layer of the sample cell irradiated by the laser pulse of fluence 1.5 J/cm^2, then due to the shock wave induced stress fracture of crystal takes place. Fig. 1 illustrates the enlarged profile of laser shock wave-induced FML of an organic crystal. It is seen that initially the FML intensity increases with time, attains a peak value and then it decreases with time, initially at a fast rate and later on at a slow rate. Eq. (10) supports this finding.

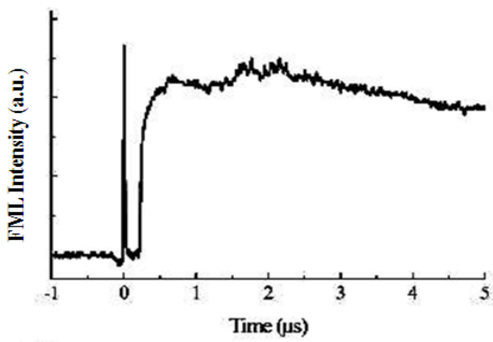

Fig.1. Enlarged profile of laser shock wave-induced FML of N-Isopropylcarbazole (NIPCz) crystals (after Tsuboi et al., ref. [5]).

Fig. 2 shows that the laser shock wave induced peak FML intensity of an organic crystal increases linearly with the applied laser fluence. This result is in accord with Eq. (12).

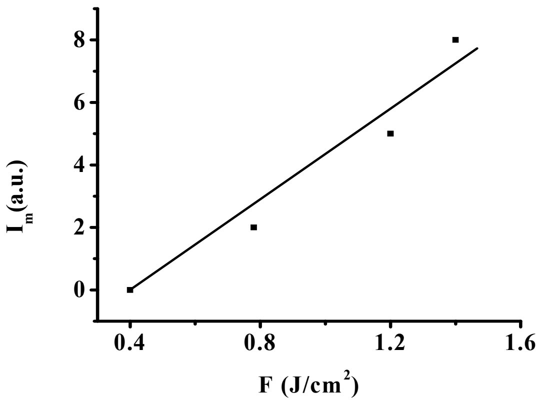

Fig.2. Dependence of the peak FML intensity on laser fluence (after Tsuboi et al., ref. [5]).

Fig. 3 shows the semilog plot of FML intensity versus ($t-t_m$). It is seen that initially the FML intensity decreases at a fast rate and then it decreases at a slow rate. Such result is evident from Eq. (14).

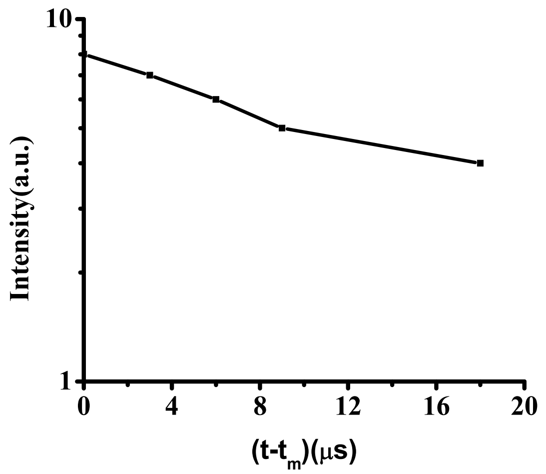

Fig.3 Semilog plot of FML intensity versus ($t-t_m$)

5. CONCLUSIONS

Laser pulse – induced shock waves as a source of mechanical stress can be used to stimulate FML. Due to the fracture caused by laser-induced shock wave, new surfaces are created in the crystal, in which the rate of creation of new surfaces is directly proportional to the exerted pressure which depends on laser fluence. Thus, the intensity of FML can be controlled by varying laser fluence. As most of the fracto-mechanoluminescent organic materials are noncentric, piezoelectrification may be behind their FML. On the basis of the rate of creation of new surfaces by laser-induced shock wave, expressions are derived for the general kinetics of FML intensity, rise of FML intensity, peak FML intensity and decay of FML intensity, in which a good agreement is found between the theoretical and experimental results.

References:

1. B.P. Chandra, Luminescence of Solids, edited by D.R. Vij, Plenum Press, New York (1998) pp 361-398.
2. B.P. Chandra, Mechanoluminescent Smart Materials and their Applications, in Electronic and Catalytic Properties of Advanced Materials, Edited by A. Stashans, S. Gonzalez and H.P. Pinto, Transworld Research Network, Trivandrum, Kerala, India, (2011) pp 1-37.
3. L.M. Belyaev, V.V. Nabatov, Yu. V. Pisarevskit and Yu. V. Shaldin, Soviet Phys. Crystallog 10 (1966) 647.
4. G.E. Hardy, B.P. Chandra and J.I. Zink Journal of the American Society/101:10/ 2788(1979).
5. Y. Tsuboi, T. Seto and N. Kitamura, J. Phys. Chem. B, 107(2003) 7547.
6. Bandis, L. Cramer, T.E. Holt, S.C. Langford, J.T. Dickinson, Applied Surface Science, 197–198 (2002) 100.
7. B.P. Chandra, V.K. Chandra, P. Jha, Journal of Luminescence 135 (2013) 139.