

Ultrasonic Wave – Induced Elastico-Mechanoluminescence of CaZnOS:Mn²⁺ / Epoxy Resin Composite

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Abstract: When UV – irradiated CaZnOS:Mn²⁺/epoxy resin composite is exposed to ultrasonic wave, then elastico-mechanoluminescence (EML) is induced and consequently an intense red light emission occurs from composite. The intensity of EML increases with increasing power of ultrasonic wave used for EML excitation. The EML of CaZnOS:Mn²⁺/epoxy resin composite can be understood on the basis of the piezoelectrically - induced electron detrapping model. Using this model, expressions are derived for the general kinetics of EML intensity, in which a good agreement is found between the theoretical and experimental results. A linear relationship between ultrasonic power and EML intensity can be understood on the basis of the proposed theory. The present investigation shows that the EML can be used to detecting the presence of ultrasonic waves, sensing and imaging of the ultrasonic wave-induced mechanical stress and also for the measurement of ultrasonic power.

Keywords: Elastico-mechanoluminescence, CaZnOS:Mn²⁺, epoxy resin, ultrasonic power

1. Introduction

Light is a form of energy which can be emitted by certain material when some other forms of energy absorbed by it. The part of the absorbed energy by a material may be re-emitted as electromagnetic radiations in the visible or near-visible region of the spectrum, in excess of thermal radiation. Such cold emission of light is known as luminescence. Luminescence can be classified on the basis of mode of excitation, stimulation, induction or the concept involved in luminescence. When the luminescence is stimulated or induced by the application of mechanical energy then it is termed as mechanoluminescence (ML). In general, ML can be classified into deformation ML (DML) and tribo ML (TML). The former is produced owing to the physical processes induced during deformation of solids, whereas the later is produced due to the contact phenomena such as triboelectricity, tribochemical reaction and tribothermal generation induced during the contact or separation of two dissimilar materials in contact. DML may further be subdivided into three types, namely, elastico ML (EML), plastico ML (PML) and fracto-ML (FML), in which the ML is induced by elastic deformation, plastic deformation and fracture of solids, respectively [1,2].

Several techniques such as loading, compressing, impulsive deformation, grinding, rubbing, cutting, cleaving, shaking, scratching, crushing, etc. as a source of mechanical energy have been used so far to stimulate or induce ML in solids. Although ML can be efficiently studied using these methods, the control of ML intensity and the timing of the detection after the application of stress is difficult. Therefore, 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 ultrasonic wave as a source of mechanical energy which can induce particle oscillations at high frequency when propagating through materials [3-5].

The magnitude of ultrasonic power can be changed from low to high value and also the exposure time can be varied. Therefore, ultrasonic wave – induced mechanical stress is more suitable to produce small mechanical deformation without fracture which is needed to induce EML in solids. As the total EML intensity varies linearly with the strain energy in the elastic region, the phenomenon of ultrasonic wave - induced EML has potential to be used in health monitoring of structures, measurement of ultrasonic power, detecting the presence of ultrasonic waves and also for the sensing and imaging ultrasonic wave - induced mechanical stress even for weak ultrasonic power [3-5]. This paper reports the ultrasonic wave – induced EML of CaZnOS:Mn²⁺ / epoxy resin composite and makes a comparison between experimental and theoretical results.

2. Theory

It has been found that the total EML intensity emitted from an elastico-mechanoluminescent material is directly proportional to its electrostatic energy. Thus, we can write

$$I_T = Z(Q - Q_{th})^2 \quad (1)$$

where, Z is a proportional constant, Q is the piezoelectric charge on the surface of the material and Q_{th} the threshold piezoelectric charge.

If d₀ is the local piezoelectric constant near the impurity in the crystal and P is the applied pressure, then the piezoelectric surface charge can be expressed as Q = d₀P.

Thus, Eq.(1) can be written as

$$I_T = Zd_0^2(P - P_{th})^2 \quad (2)$$

Differentiating Eq (2), we get

$$\frac{dI_T}{dt} = I = 2Zd_0^2 (P - P_{th}) \dot{P} \quad (3)$$

Eq.(3) indicates that the ML should appear after a particular threshold pressure P_{th} and it should increase linearly with the applied pressure P as well as with the pressure rate \dot{P} . As ultrasonic work power is the rate of emission of ultrasonic energy which induces required pressure for the stimulation of ML in the material. Thus, according to Eq. (3), the ML intensity I should be proportional to ultrasonic power.

3. Experimental Support to the Proposed Theory

Fig.1 shows the schematic diagram of experimental setup generally used for the sensing and imaging of the ultrasonic wave – induced ML from EML material [3]. Similar arrangement has been used by Zhang et al. [4] for the measurement of applied ultrasonic work power. Ultrasonic fountain at frequency 20 MHz with an output power of 2.94 mW which is applicable for medical purpose used by them. They have used a stress sensitive film prepared by the homogeneous dispersion of CaZnOS:Mn^{2+} particles into an epoxy resin matrix as a EML material.

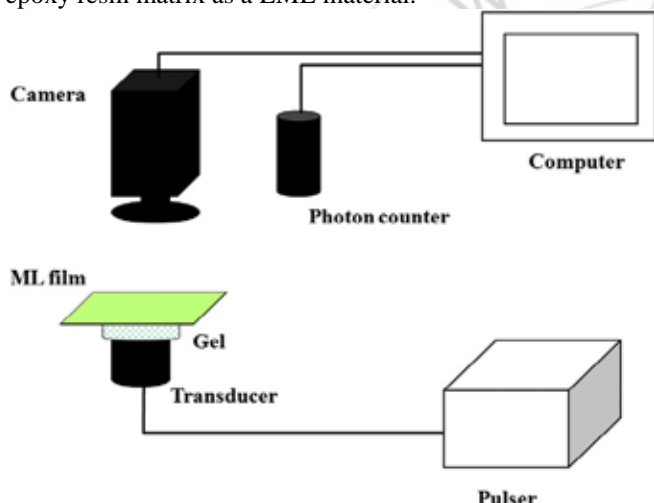


Figure 1: Schematic diagram of experimental setup for ultrasonic output power measurement (after Terasaki et al., ref. [3]).

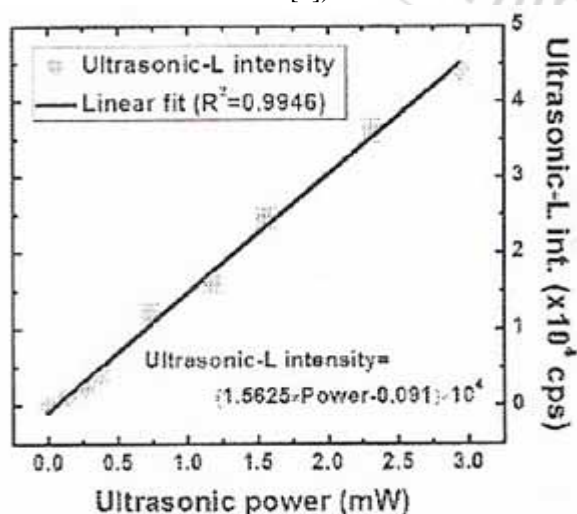


Figure 2: Relationship between ultrasonic wave – induced EML intensity and applied ultrasonic power (after Zhang et al., ref. [4]).

Fig.2 shows the relationship between ultrasonic wave – induced EML intensity and applied ultrasonic power. It is seen that ultrasonic wave – induced EML intensity linearly increases with increase of applied ultrasonic power. It implies that even for weak applied ultrasonic power, ultrasonic vibrations can be efficiently sensed and corresponding ultrasonic power can be evaluated simultaneously by using a stress sensitive elasto-mechanoluminescent film of CaZnOS:Mn^{2+} /epoxy resin composite. Eq. (3) supports this finding.

4. Conclusions

When UV – irradiated CaZnOS:Mn^{2+} /epoxy resin composite is exposed to ultrasonic wave, then elasto-mechanoluminescence (EML) is induced and consequently an intense red light emission occurs from. The intensity of EML increases with increasing power of ultrasonic wave used for EML excitation. The EML of CaZnOS:Mn^{2+} /epoxy resin composite can be understood on the basis of the piezoelectrically - induced electron detrapping model. Using this model, expressions are derived for the general kinetics of EML intensity, in which a good agreement is found between the theoretical and experimental results. A linear relationship between ultrasonic power and EML intensity can be understood on the basis of the proposed theory. The present investigation shows that the EML can be used to detecting the presence of ultrasonic waves, sensing and imaging of the ultrasonic wave - induced mechanical stress and also for the measurement of ultrasonic power. Therefore, EML has potential in low intensity ultrasonic measurement on biological tissues in medical applications.

References

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