Journal of Luminescence 131 (2011) 1203–1210

Contents lists available at ScienceDirect

Journal of Luminescence

journal homepage: www.elsevier.com/locate/jlumin

Development of mechanoluminescence technique for impact studies

B.P. Chandra *

Disha Academy of Research and Education, Disha Institute of Management and Technology, Satya Vihar, Vidhansabha-Chandrakhuri Marg, Raipur 492101 (C.G.), India

ARTICLE INFO

Article history:
Received 3 August 2010
Received in revised form
19 February 2011
Accepted 22 February 2011
Available online 1 March 2011

Keywords:
Mechanoluminescence
Triboluminescence
Impact
Phosphors
Piezoelectricity

ABSTRACT

A new technique called, mechanoluminescence technique, is developed for measuring the parameters of impact. This technique is based on the phenomenon of mechanoluminescence (ML), in which light emission takes place during any mechanical action on solids. When a small solid ball makes an impact on the mechanoluminescent thin film coated on a solid, then initially the elastico ML (EML) intensity increases with time, attains a maximum value I_m at a particular time t_m, and later on it decreases with time. The contact time T_c of ball, can be determined from the relation $T_c=2t_c$, where t_c is the time at which the EML emission due to compression of the sample becomes negligible. The area from where the EML emission occurs can be taken as the contact area A_c. The maximum compression h is given by $h=A_c/(\pi r)$, where r is the radius of the impacting ball, and thus, h can be determined from the known values of A_c and r. The maximum force at contact is given by $F_m=(2mU_0)/T_c$, where m is the mass of the impacting ball and U_0 is the velocity of the ball at impact. The maximum impact stress σ_m can be obtained from the relation, $\sigma_m=F_m/A_c=(2mU_0)/(T_cA_c)$. Thus, ML provides a real-time technique for determining the impact parameters such as T_c, A_c, h, F_m and σ_m. Using the ML technique, the impact parameters of the $SrAl_2O_4$:Eu film and ZnS:Mn coating are determined. The ML technique can be used to determine the impact parameters in the elastic region and plastic region as well as fracture. ML can also be used to determine the impact parameters for the collision between solid and liquid, if the mechanoluminescent material is coated on the surface of the solid. The measurement of fracto ML in microsecond and nanosecond range may provide a tool for studying the fragmentations in solids by the impact. Using the fast camera the contact area and the depth of compression can be determined for different intervals of time.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Mechanoluminescence (ML) is a type of luminescence induced by any mechanical action on solids. The light emissions induced by elastic deformation, plastic deformation and fracture of solids are called elastico ML (EML), plastico ML (PML) and fracto ML (FML), respectively [1]. Nearly 50% of all inorganic salts and organic molecular solids show FML; however, only a few solids exhibit EML and PML. Although the phenomenon of ML is known for a long time, up to the end of twentieth century, no remarkable practical application of mechanoluminescent materials could be made because of their low ML intensity and lack of reproducibility. In the last decade, a variety of materials have been obtained that emit an intensive and repeatable EML during their elastic deformation without any destruction [2–21]. The EML of $SrAl_2O_4$:Eu, $SrMgAl_6O_{11}$:Eu, $Ca_2Al_2SiO_7$:Ce, ZrO_2:Ti, etc. is so intense that it can be seen in day light with naked eye and the EML appears for several tens of seconds after the elastic deformation. The elastico-mechanoluminescent materials possessing intensive and repeatable EML are useful in stress sensor [10,19], and in the real-time visualizations of stress distribution in solids [10,15,21], stress field near crack-tip [14], and quasidynamic crack-propagation in solids [22,23]. Furthermore, the EML materials have potential for developing new-generation optical sensors for recording defects and damages, and also for developing a safety-monitoring network system using EML sensors.

As ML is produced during the impact of an object on the mechanoluminescent material coated on a solid, systematic correlation between ML and the impact parameters of an object is expected. Generally, impact is defined as a sudden change in the momentum of each contacting body, without a corresponding change in position. Impact is inherent to unilateral constraints, that is, a constraint that acts at a given instant only in one direction of the common normal of contacting surfaces. The subject of impact has attracted the interest of scientists, engineers and technologists from a large number of areas of knowledge ranging from astrophysics to robotics. The common goal of many researchers in impact studies is to develop theories that can predict the behavior of colliding objects. The mechanical engineer's interest in impact problems is motivated by the desire to develop valid models for mechanical systems where impact is

* Tel.: +91 0771 2263650; fax: +91 0771 24720100
E-mail address: bpchandra4@yahoo.co.in

0022-2313/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jlumin.2011.02.027

inherent in their function, e.g., crushers, circuit breakers, presses, etc. Some other issues such as play in joints and damages due to accidental or functional impact are also important to understand. In the past, Hertz theory of impact has played a very important role in understanding and advancement of the phenomenon of impact. In the evolution of impact theory four major aspects have emerged as distinct subjects of interest. These four aspects are: classical mechanics, elastic stress wave propagation, contact mechanics and plastic deformation. Depending on impact characteristics (velocity, materials), the assumptions made and the results sought, one aspect becomes more predominant than the others and thus it leads to a satisfactory solution to the impact analysis [24–29].

Contact time, contact area, maximum compression, maximum impact force, maximum impact stress and coefficient of restitution are the important parameters of impact. The present paper reports that mechanoluminescence provides a unique technique for determining the contact time, contact area, maximum compression, maximum impact force and maximum impact stress produced during the impact of a ball on solids. It is to be noted that, whereas for a long time impact was used to excite ML in solids [30–34], reversing the trend, in the present paper the ML is used to study the impact. It is shown that the ML technique for impact studies is superior to the conventional techniques.

2. Mechanism of elastico-mechanoluminescence

The EML emission cannot arise due to the direct conversion of mechanical energy into the light energy as the mechanical energy in the elastic region is much less.

There is a possibility of EML excitation by the bending segments of charged dislocations, whereby the bending segments of charged dislocations between the pinning point defects may interact electrostatically with the filled hole-traps and the released holes may recombine with the reduced activator ions and subsequently luminescence may be produced. There is also a possibility that the electrons released during the electrostatic interaction between charged dislocation segments and filled electron traps may be captured in the excited state of activator ions and light may be produced during the de-excitation of excited activator ions [4–6,8,9,19]. The dislocation model of EML does not seem suitable because of the following reasons: (i) only the piezoelectric phase of Eu^{2+}-doped strontium aluminates show EML and the non-piezoelectric phases do not show EML [12], (ii) as the area swept out by the bending segment of dislocations is directly proportional to the applied stress, the total EML intensity should increase directly with stress [3]; however, the total EML intensity has been found to increase directly with the square of stress and (iii) crystals show EML only in the presence of particular impurity, e.g., ZnS crystals show EML when they are doped with Mn^{2+}, but ZnS crystals do not show ML when they are doped with Cu^{1+} or Ag^{1+}.

There is a possibility that the macroscopic or bulk piezoelectric field may cause detrapping of the charge carriers and subsequent capture of electrons with the excited state of activator ions or recombination of holes with reduced state of the activator ions may cause the light emission [10,7,11–13]. Generally, the piezoelectric constant d of the crystals is of the order of 10×10^{-12} C N^{-1}, and the threshold pressure P_{th} for the EML emission is nearly 10^6 N m^{-2}. For the dielectric constant ε of the order of 10, the piezoelectric field, is, $F=Q/(\varepsilon_0\varepsilon)=10^5$ V m^{-1}, where $Q=dP$, is the piezoelectric charge, and $\varepsilon_0=8.85\times10^{-12}$ C N m^{-2},is the permittivity of space. The electric field of the order of 10^5 V m^{-1} cannot cause the impact excitation, as this process needs an electric field of the order of 10^8 V m^{-1}. Also, the electric field of the order of 10^5 V m^{-1} cannot cause the detrapping of traps. Furthermore, the piezoelectric model is not able to explain the occurrence of EML in centrosymmetric crystals, and moreover, it cannot explain the appearance of EML only in the presence of certain specific impurities in crystals.

The local electric field near the defect centers is higher as compared to that of the normal regions and it may cause the detrapping and subsequently the EML emission. The suitability of the localized piezoelectrically induced detrapping model of EML becomes evident from the following facts: (i) the piezoelectric constant is higher near the defect centers [35], (ii) although ZnS is piezoelectric, it shows EML only in the presence of particular dopants such as Mn^{2+}, and it does not show EML in pure form and also for the Cu^{1+} or Ag^{1+} dopants, (iii) several crystals exhibit FML and EML in impure form and when they are purified, they do not show ML [1,9,36–38], (iv) generally, the crystals show EML only in the presence of particular activator ions, (v) only the piezoelectric phase of Eu^{2+}-doped strontium aluminates shows EML and the non-piezoelectric phases do not show EML and (vi) according to the localized piezoelectrically induced detrapping model, the total EML intensity should increase quadratically with the applied pressure, which is fairly in accord with the experimental observation.

The EML of luminescent crystals having filled traps can be understood with respect to the following steps:

(i) The application of pressure produces local piezoelectric field near the activator ions, which may be high due to the change in the local structure.
(ii) The local piezoelectric field reduces the trap-depth of the traps lying near the activators.
(iii) The decrease in trap-depth causes transfer of electrons from electron traps to the conduction band or transfer of holes to the valence band.
(iv) In case of the crystals such as $SrAl_2O_4$:Eu^{2+}, some of the detrapped electrons reaching and moving in the conduction band are captured in the excited state of the activator ions located adjacent to the bottom of the conduction band, whereby excited ions are produced [39–41], and the de-excitation of excited activator ions gives rise to the light emission characteristic of the ions. Similarly, if there is detrapping of holes, then they may recombine with the reduced state of activators and luminescence may be produced. In the case of ZnS:Mn crystals, the detrapped electrons reaching and moving in the conduction band may recombine with the holes, and subsequently, the energy released during electron–hole recombination may excite the Mn^{2+} ions and consequently the de-excitation of excited Mn^{2+} ions may give rise to the light emission.

There is also a possibility that the increasing energy level of trapped electrons owing to the localized piezoelectric field may cause tunneling of electrons to the excited energy level of the activator ions and thereby luminescence may be produced, where the transfer of electrons to the conduction band does not take place. This process can be ruled out on the basis of the following facts: (i) the tunneling model suggests that the total EML intensity should be directly proportional to the applied pressure, but practically it is directly proportional to the square of applied pressure, and (ii) this process is not capable of explaining the slow decay of EML.

3. Parameters of impact and basic principle of the ML technique for impact studies

3.1. Parameters of impact

Consider a sphere of mass m, radius r, density ρ and elasticity Y impacting on an infinite flat plate with a velocity U_0. Using the

Download English Version:

https://daneshyari.com/en/article/5402019

Download Persian Version:

https://daneshyari.com/article/5402019

Daneshyari.com