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Ball impact induced elastico-mechanoluminescence for impact sensor

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ABSTRACT

In this paper, we report on the elastico-mechanoluminescence (EML) from $Sr_{0.97}Al_2O_4:Eu_{0.01}$, $Dy_{0.02}$ phosphor composite film. The film is prepared on polycarbonate substrate by mixing of $Sr_{0.97}Al_2O_4:Eu_{0.01}$, $Dy_{0.02}$ phosphor with optical resin. The EML induced by impulsive excitation using a steel ball is measured. The ML intensity increases linearly with square of impact velocity of the steel ball. This study is useful to get ML information when a projectile with small contact area, such as steel ball makes an impact on the ML sensitive composite film.

1. Introduction

Mechanoluminescence (ML) is a type of luminescence induced by any mechanical action on solids. Mechanoluminescence is categorized into three parts: elastico-ML (EML), plastico-ML (PML) and fracto-ML (FML) [1,2]. Till 1950, the reports were available on fracto-mechanoluminescence (FML) only, but this method was not useful in the development of nondestructive sensors [3]. In this connection, all efforts were made for the development of nondestructive mechanoluminescent materials. Elastico-mechanoluminescence (EML) is a nondestructive mechanoluminescence which is reproducible. EML gives light during elastic deformation of ML sample. EML offers advantages such as repetitive, wireless, non-destructive, reproducible, real-time and reliable stress sensing [4].

In 1992, Chandra and Bisen [5] reported on the elastico- mechanoluminescence (EML) of γ-irradiated LiF crystals. Chandra [6] published a theoretical paper in 1996 discussing several aspects of EML and PML of crystals. It has been reported that EML exhibits nondestructive and reproducible ML [6]. In 1998, Akiyama et al. [7] were the first to report the EML from $Sr_3Al_2O_6$:Eu, Dy. They observed that EML in $Sr_3Al_2O_6$:Eu, Dy and $SrAl_2O_4$:Eu, Dy phosphors was so strong that it could be seen in day light with naked eyes, and the ML intensity was about 500 times higher than the sugar crystals [8]. Xu et al. [9,10] and Akiyama et al. [11] have shown that the stress distribution in solids can be visualized using the nondestructive elastico- ML.

Xu et al. [12] opened new avenues in the field of mechanoluminescence by demonstrating EML with the impact of steel ball on ZnS film. They reported that the prepared film was very sensitive to mechanical stimuli, and could be used in detecting various mechanical stresses and developing stress sensors. Recently, Jeong et al. [13] reported extremely bright and durable ML flexible composite films. Their films could bear mechanical stresses of over ≈100000 times repeated by using a combination of copper-doped zinc sulfide (ZnS: Cu) and polydimethylsiloxane.

Limited studies have been undertaken on the EML induced by the impact of the moving steel ball on to the flexible phosphorescent films till date [12,13]. Thus, there is a need to study EML produced by impact of the steel ball in more detail. In the recent past, efficient EML materials showing potential for sensors, light sources, colored displays, etc. [7–21,27,28] have been developed and studied theoretically [7–28]. Xu et al. [29] reported that only monoclinic *P*21/*n* crystal structure of $SrAl_2O_4$:Eu phosphor showed an intense EML. The $SrAl_2O_4$:Eu, Dy phosphor has been a widely investigated and very intense ML material in recent past [8,30,31]. Lin et al. [31] reported that the $Sr_{0.97}Al_2O_4:Eu_{0.01}$, $Dy_{0.02}$ phosphor gave the brightest ML emission. Here in, we report on the EML induced by the impact of a steel ball on to the $Sr_{0.97}Al_2O_4:Eu_{0.01}$, $Dy_{0.02}$ phosphor composite film mixed with optical resin on polycarbonate substrate. This study is useful to get more information on ML, when a projectile with small contact area such as steel makes an impact on the ML sensitive composite film.

2. Experimental

The $Sr_{0.97}Al_2O_4:Eu_{0.01}$, $Dy_{0.02}$ phosphor was prepared by the

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previously reported method [32]. Initially, the appropriate amounts of constituent materials $SrCO_3$, Al_2O_3, Eu_2O_3 and Dy_2O_3 were mixed and pressed into pellet. Subsequently, the pellets were pre-sintered in a furnace at 1000°C for 5 h in air. In this heat treatment, where a small amount of boric acid (H_3BO_3) was used as a flux, solid state reaction took place among strontium carbonate ($SrCO_3$), aluminum oxide (Al_2O_3), europium oxide (Eu_2O_3) and dysprosium oxide (Dy_2O_3). Then the pre-sintered pellets were ground and sintered again at 1350°C for 5 h in a reducing atmosphere of Ar + 5%H_2 flow [32].

After sintering in reduced atmosphere, the so obtained hard compact masses of phosphor were ground. This powder sample was then mixed with an optical resin (Polyurethane optical resin) in the 1:1 ratio. A film of this mixture was deposited onto the Lexan polycarbonate substrate at 60 °C for 1.5 h using doctor blade method [33]. The thickness of the deposited film was 380 µm. For the measurement of EML intensity, a small ball having mass 16.31 g and diameter 1.67 cm was dropped on the ML composite film from different heights (10–60 cm). At each dropping height, ten tests were performed to obtain an average ML intensity for the same sample.

The EML was triggered by dropping steel ball on $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ ML composite film placed on the sample holder. The schematic diagram of ML experimental set-up is shown in Fig. 1 (1-PVC pipe, 2-steel ball, 3-mechanoluminescent film, 4-photomultiplier tube, 5- stand, 6- sample holder, 7-wooden block, 8-iron base mounted on a table). The impact force is produced when the steel ball falls from a fixed height through PVC pipe on the ML composite film. The emitted ML light was recorded on an RCA-931A photomultiplier tube (PMT) placed just below the sample holder. The response time of PMT system was nearly 5 µs. The EHT of PMT is kept 400 V. The output of the PMT was fed to a digital storage oscilloscope (DSO). All the experiments were carried out at room temperature.

3. Results and discussions

Fig. 2 illustrates the time dependence of EML intensity of $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ composite film for impact velocity at 198 cm/sec. It was seen that as the steel ball makes an impact onto the $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ composite film, initially the EML intensity increases with time, attains peak/maximum at a particular time t_m, followed by a decrease with time. In the time vs EML curve, two peaks are found. As can be seen in Fig. 2, there are recorded two ML peaks, out of which the intensity of first peak is higher than the second peak. This may be due to the fact that first peak is due to de-excitation of Eu^{2+} ions [32] during the impact of steel ball while second peak occurs during bouncing of steel ball, due to detrapping of electrons from the shallow traps, which are trapped during the impact.

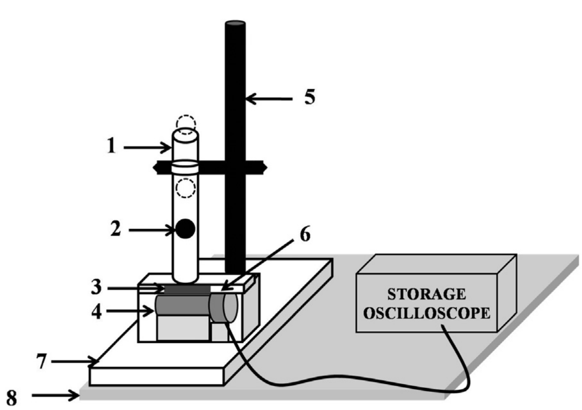

Fig. 1. Schematic diagram of the experimental arrangement used for measuring the time dependence of ML in crystals (1-PVC pipe, 2- steel ball, 3-mechanoluminescent film, 4-photomultiplier tube, 5- stand, 6- sample holder, 7-wooden block, 8-iron base mounted on a table).

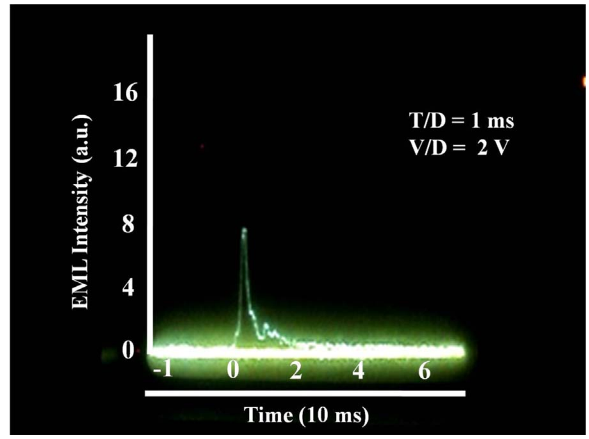

Fig. 2. Snap shot of the time dependence of the ML intensity for $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ phosphor composite film during impulsive excitation of the sample.

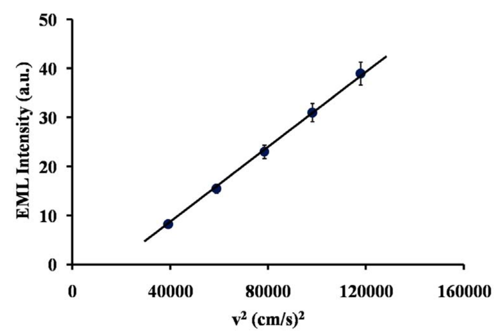

Fig. 3. Variation of ML intensity with the square of impact velocity for $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ phosphor composite film.

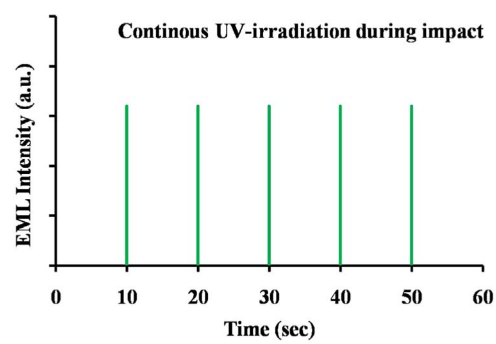

Fig. 4. Variation of ML intensity with time under continuous UV irradiation for $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ phosphor composite film.

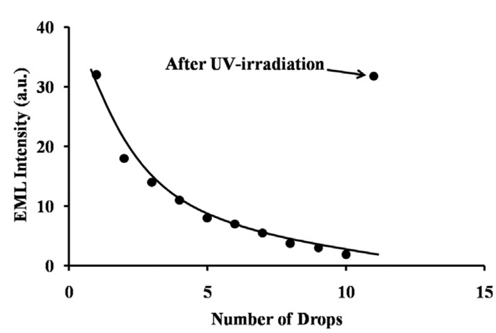

Fig. 5. Dependence o ML intensity on the number of droppings of a steel ball on $Sr_{0.97}Al_2O_4$:$Eu_{0.01}$, $Dy_{0.02}$ phosphor composite film.