Mechanoluminescence Of Rare Earth Doped Potassium Aluminum Silicate Phosphor

Renu Nayar and Vinit Nayar

Abstract The authors desired to expand the base of knowledge and application of ML-induced impacts with the specific goal of demonstrating the potential of phosphor based impact sensors. When a $KAlSiO_4$:Dy samples are deformed impulsively by applying a load from a fixed height, then initially the ML intensity increases with time, attains a peak value I_m at a particular time tm, and later on it decreases with time. The peak intensity I_m increases linearly with the increasing height of the load. After t_m, initially the ML intensity decreases at a fast rate, and later on it decreases at a slow rate. Light was generated from the interaction of a dropped mass and a small number of luminescence centers in the $KAlSiO_4$: Dy powder. The ML in $KAlSiO_4$: Dy samples can be understood on the basis of the piezoelectrically -induced electron detrapping model, in which the local piezoelectric field near the Dy^{2+} centres reduces the trap-depth, and therefore, the detrapping of filled electron traps takes place, and subsequently the energy released non-radiatively during the electron-hole recombination excites the Dy^{2+} centres and de-excitation gives rise to the ML.

Keyword ML-Induced, potential of phosphor, piezoelectrically

1. INTRODUCTION

Phosphors are materials doped with impurities that give off cold light when excited. This fluorescence is caused by ions in the lattice structure emitting a photon to de-excite, versus non-luminescent phonon processes. Light emitted from a phosphor is not caused by thermal effects, and as such, is considered ''cold''. Fluorescent light bulbs and traditional cathode ray tube (television) pixels are examples of phosphor applications. There exist many different excitation sources, such as photons (photoluminescence), electrons (cathode luminescence), and ionizing radiation (radio luminescence). Excitation of phosphors by crystal stress or fracture, known as mechanololuminescence (ML), has been observed in such crystals as sulphate, phosphate, silicate etc. for many centuries.Phosphor materials are used in a variety of applications including television screens, lighting, photocopy lamps, scintillators, as X-ray conversion screens and sensor technology. The materials used for these sensors are typically inorganics doped with impurities that provide characteristic fluorescence and are commonly referred to as phosphors. Sensor technologies based on these materials use characteristics of the light emission to determine various parameters such as temperature, impact/pressure, and radiation dose. The development of a health-monitoring sensor suite requires many individual measurements that must survive and operate in the harsh environment of space. This environment includes wide temperature swings, radiation exposure of all types and energies, and particle impact. In addition, the sensors must also be lightweight and minimally intrusive system.When a ML crystal is fractured, electrons are torn away from their parent atoms, resulting in a static discharge across the gap of the fracture.

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The light is emitted by several distinct, material dependent mechanisms. The emission spectrum for sugar indicates that the light comes from the atmospheric nitrogen that fills the gap during fracture. This is the same source of light as that from lightning or touching a doorknob on a dry day. Spectra for other samples show emission characteristic of the material as well as nitrogen lines. Such spectra suggest a secondary energy process. Other substances exhibit a spectrum characteristic of the material alone. While charge separation is the same in all cases, the emission mechanism depends on the material. The studies on the ML produced during pulse–induced exitation in crystals has been interesting as it provides important information concerning the nature of the luminescence centre's and helps in understanding their basic mechanism of ML excitation in solids. Mechanoluminescence is the light emission induced as a result of a mechanical action on a solid. About 36% of all inorganic and 19% of all organic compounds exhibit ML [1, 2]. The development of mechanoluminescence-based method for monitoring of size reduction processes in stirred media mill is reported by Sergej Aman and Jqrgen Tomas [3]. It is a wide-band gap semiconductor, which occurs naturally as the mineral gahnite and is a member of the spinel family; it can be used as transparent conductor, dielectric material, and optical material [4, 5]. ML materials with a high intensity have been developed, showing promising applications of this phenomenon in stress sensing techniques [6-8]. Synthesis and thermo luminescence properties of SrAl2O4 (EU) phosphor irradiated with cobalt-60, 6 MV and 16 MV photon beams [9]. Ag nanoparticles coated $CaTiO_3$: Eu phosphor obtained from charge attracting process shows higher PL intensity and enhanced heat dissipation than the uncoated ones due to the LSPR effect and heat conduction of Ag nanoparticles reported by Zhenhu et al. [10]. The objective of this work is to study the ML properties of $KAlSiO_4$: Dy phosphor, for ML sensors and dosimeter use, ML properties should be known and optimum intensity of ML material is required. The present paper reports various ML properties in gamma-irradiated $KAlSiO_4$: Dy phosphors. The luminescent properties of a $KAlSiO_4$: Dy phosphor depend on the details of its electronic band structure. These are determined by the host molecule and by the type and quantity of dopant used. Incident particles, such as electrons or protons could displace the doping atoms, altering the band structure.

2. EXPERIMENTAL DETAIL

The experimental setup used for impulsive excitation of ML in γ- irradiated impurity doped phosphate phosphors is as follows; the sample was placed on the upper surface of a transparent Lucite plate. It will be covered with a thin aluminum foil and fixed with adhesive tape. The load of different masses was dropped from different heights and the impact velocity of the load was changed. For taking ML measurement the phosphor was placed on a transparent Lucite plate, inside a sampler holder below the guiding cylinder and the luminescence was monitored below the transparent plate using an RCA 931A photomultiplier tube connected to a storage oscilloscope (SCINTIFIC HM-205). The photomultiplier housing is made of thick soft iron to provide a shielding from light and magnetic field. The slit arrangement at the window is provided to adjust the size of the window according to the incident beam. The ML intensity was monitored by the photomultiplier tube whose output will be fed to one channel of storage oscilloscope. For determining the peak intensity, peak position, rise and decay time of ML, trace on the oscilloscope screen was recorded on tracing paper.

3. RESULT AND DISCUSSION

In 1999, research was completed to determine the effect of repeated impacts on ML yield for a given impact energy. Example results for an impact energy are shown in Fig. 1. The smooth curve is the best-fit line for the accumulated data. Results show that after six impacts, the PMT output potential dropped to about 0.3 meter height. Repeated impacts reduces the number of undamaged impurity centers in the $KAlSiO_4$: Dy which also reduces the corresponding ML yield. ML yield versus drop number for an irradiated $KAlSiO_4$: Dy sample with an impact velocity 30m/s. Repeated impacts will reduce the ability of the sensor to generate ML and increase the probability of errors into the system.. The samples used in this test were also made by coating aluminum coupons half the thickness of the ones used in this experiment. Because the substrate was thinner, it was possible to strike the sample on the back and extend the life of the coating compared to direct impact.

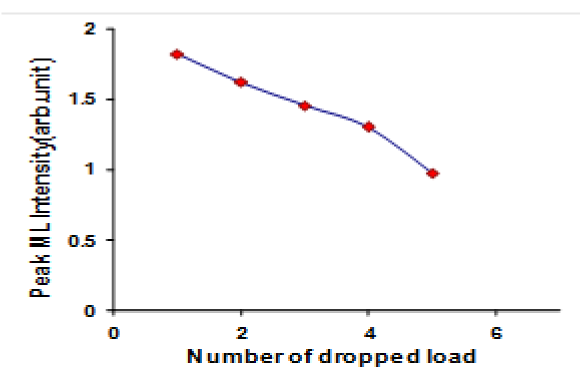

Figure 1 *Results for an impact energy*

To extend this research, it was decided to measure the ML emission intensity as a function of drop number for annealed. As is shown in Fig. 1, the ML emission intensity decreases with drop number. Notice that the ML emission intensity drops more rapidly for the annealed samples compared to the ones that are not annealed. The annealed silicate appeared to delaminate and crumble more easily with successive drops when compared to the other samples that were not annealed. Annealing appears to make the paint more susceptible to damage. This result could be caused by differences in thermal expansion between the $KAlSiO_4$: Dy silicate and the aluminum substrate. Additional research will be completed to further quantify these results

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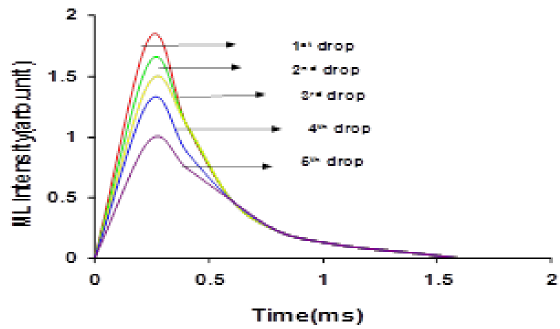

Figure 2 *Variation in ML emission*

It should be noted that variations in silicate thickness and composition play a significant role in the amount of ML light intensity generated from a given impact. No attempt was made to measure the absolute light emission. These samples were originally made and irradiated to complete the research. Based on observational evidence, ML emission varied as much as 20% between drops. However, for most drops, variation in ML emission was much less than this value as shown in Fig. 2. In this example, both the peak intensity and ML emission duration were very similar for each of the five drops. Fig.3 shows the ML intensity of the gamma irradiated rare earth doped phosphate based phosphors depends upon the impurity concentration. ML intensity first increases with concentration of dopant, attains maximum value for a particular concentration then decrease with further increase in dopant concentration. For $KAlSiO_4$: Dy phosphor the maximum ML intensity is observed at 0.5 mol% concentration of impurity.

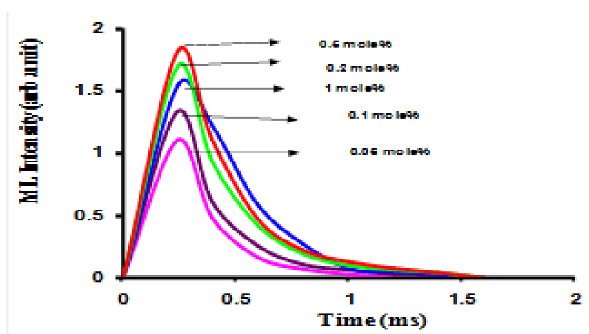

Figure 3 *The ML intensity of the gamma irradiated rare earth doped phosphate based phosphors*

Fig.4 shows ML intensity increases with increasing impact velocity of the piston. Fig.5 shows the total ML intensity initially increases linearly with increasing impact velocity of the piston then it attains a saturation value for higher value of impact velocity for $KAlSiO_4$: Dy samples.

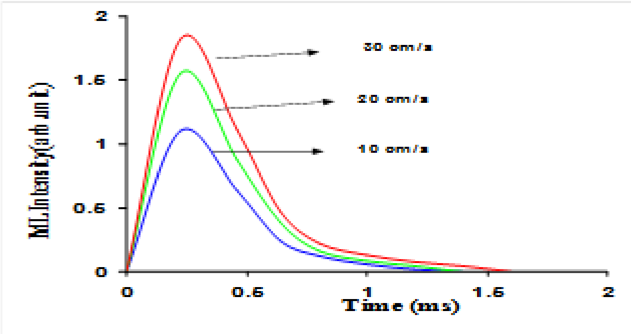

Figure 4 *ML intensity increases with increasing impact velocity of the piston*

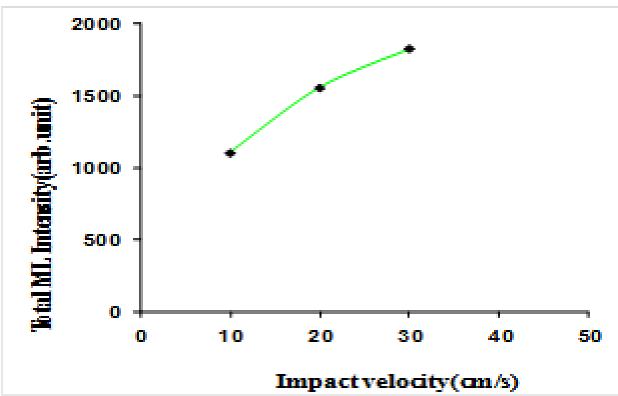

Figure 5 *The total ML intensity increases linearly with increasing impact velocity of the piston*

Fig. 6 shows the ML intensity increases with increase in mass of the load without any appreciable change in time corresponding to ML peak for $KAlSiO_4$: Dy samples. Fig.7 shows the total ML intensity initially increases linearly with increasing mass of the piston then it attains a saturation value for higher value of impact velocity for all samples.

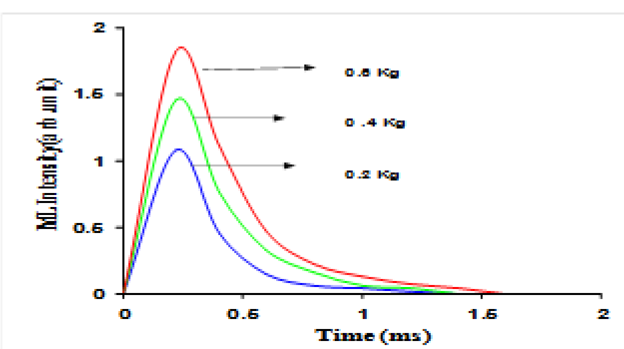

Figure 6 *The ML intensity increases with increase in mass of the load*

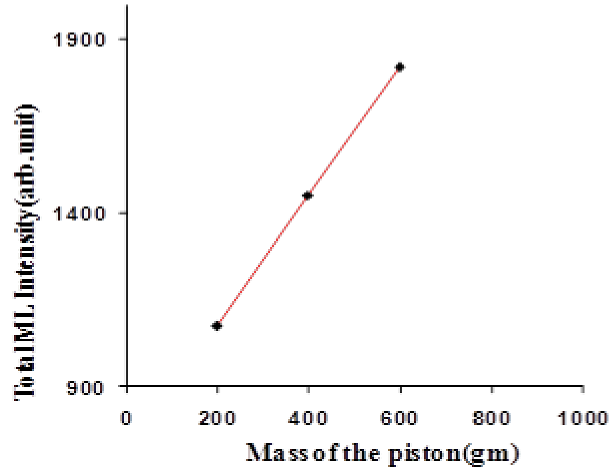

Figure 7 *The total ML intensity initially increases linearly with increasing mass of the piston*

So, a more appropriate measure may be intensity as of function of the impact energy normalized by impact area. From these results, the authors desired to expand the base of knowledge and application of ML-induced impacts with the specific goal of demonstrating the potential of phosphor based impact sensors. Such events as the loss of the Columbia orbiter demonstrate the need for sensors to detect impact. Given the author's previous research experience, it was felt that the state of phosphor-based impact detection had matured to the point of detection of hypervelocity impact.

4. CONCLUSIONS

The emission of light due to ML is a phenomenon that has been known for centuries. The development of a health-monitoring sensor requires many individual measurements that must survive and operate in the space radiation environment. Light was generated from the interaction of a dropped mass and a small number of luminescence centers in the $KAlSiO_4$: Dy powder. Results from these measurements indicate that ML from $KAlSiO_4$: Dy was detected from the impact of a 30m/s aluminum projectile with a silicate target. More ML research needs to be completed to further phosphor-based impact detection. The production of ML light needs to be investigated in the hypervelocity regime in order to make predictions for impact characteristics. Such velocity or energy predictions make a potential sensor more useful than a simple binary (impact or no impact) system. The measurement of the ML spectra is also very useful for the development of an impact sensor. The authors plan to measure the ML spectrum for $KAlSiO_4$: Dy produced by a hypervelocity impact in a future series of experiments. Given the large number of ML phosphors, future investigations should include phosphors other than $KAlSiO_4$:Dy. By careful consideration of the environment where impact detection is desired, other phosphors may offer ML at more useful wavelengths and be more radiation resistant. Also, other ways to apply a phosphor coating have been used in sensing, and these are also worth investigating.

5. REFERENCES

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