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Recent Advances in Mechanoluminescence

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Abstract

The non thermal emission of light in response to mechanical stimulation on solid material is known as mechanoluminescence. While this phenomenon has been noted in breaking of some material for a long time, it is currently the subject of intense research, particularly to find non destructive mechanoluminescence during elastic deformation. Although many materials have already been found to be mechanoluminescent, there is still an urgent need for new ones with adjustable colour and enhanced sensitivity. It is still unclear the physical cause of phenomenon which primarily involves release of trap carrier at defects via inducing stress. This ultimately prevents more in depth research, whether it to be theoretical or application focused. Here we would focus on clear understanding of mechanoluminescence phenomenon, proven and its application to various fields such as in ultrasonic field, mechanoluminescence phosphors, stress distribution etc.

Keywords: Mechanoluminescence, Mechanism, recent potential applications

Introduction

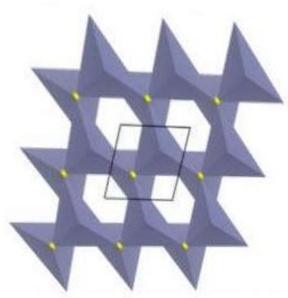
Mechanoluminescence in a broad sense, refers to the luminescence that occur in reaction to mechanical stimulus according to amount of stress, mechanoluminescence refer to luminescence caused by elastic deformation (elasticoluminescence) or fracture (fractoluminescence), plastic deformation (plasticoluminescence). Scientists are eager to study mechanoluminescence upon non destructive elastic deformation as a result of the discovery of elastoluminescence, particularly in phosphors, in the late 1900s. This mechanoluminescence based techniques has calculated the stress distribution of composite during compression construct on linearity between mechanoluminscence intensity and stress under tensile load Mechanoluminescence substances displaying mild emission through mechanical stimulus have attracted dazzling attention synthetic skins, mild emission of fabric, optical imaging etc. In later 1600s, the primary discovery of the mechanoluminescence phenomenon a massive variety of inorganic and natural mechanoluminescence substances has been suggested. However maximum of these mechanoluminescence substances are now no longer almost used due to their adverse characteristics. Only some determined substances with self recoverable mechanoluminescence with inside visible range have eventually occurring in above mentioned application field.

Crystal structure and their relation to mechanoluminescence

Rock salt compounds

Colour centres arise in rock salt compounds built up with edge sharing octahedra are often generated by irradiation with X- rays, gamma rays or treatment with vapor of metal. Dislocations of these single crystals are tends to slip because critical stress is approximately 1mpa. Mechanoluminescence found in coloured alkali halides in early 1900s but not usually in non irradiated alkali halides provide light during deformation. Mechanoluminescence takes place even at low level of stress and its intensity is linear to the stress but only proportional to mechanical strength during plastic deformation.

ZnS correspondent of rock salt structure is hexagonal tightly packing of connected layers by tetrahedra sharing common anions. Layers are in fashion ABABA.....along (001) plane. Mechanoluminescence has was found in Zns doped with Cu+ or Mn2+ which is said to arise from interaction between piezoelectricity and flat acceptor and donor levels. It remains uncertain how these recuperate mechanoluminescence intensity to original level in consecutive cycles even tough retrapping electrons within conduction band has been proposed for such phenomenon



Structure of ZnS (fig.1)

The particularly small wide variety of mechanoluminescence compounds no longer apparently justify an specific hyperlink between crystal and the overall performance of mechanoluminescence, however for maximum compounds emission occurrence in mechanoluminescence are similar to the photoluminescence. The vital triggers of mechanoluminescence are observed inside the unique crystal shape, point defects, microstructures, along with domain. Point defects and their cluster formation create suitable trap for charge carriers. Under stress, their geometric structure changes, resulting in the shift in binding energy for trapped charges, which can also additionally create the get away of trapped charges. It is noticeable that centrosymmetry can be damaged via way of means of piezoelectricity and point defects can accordingly be observed. In this context, connection with anisotropy in elasticity or piezoelectricity is favorable for development of mechanoluminescence phosphors since internal electric field in crystallographic direction can be large enough to induce observable mechanoluminescence. The survey indicates more or less 75% of mechanoluminescence phosphors have certain systems wherein anisotropy with inside the elasticity may be expected. They have an impact on of microstructure may be essential in numerous cases.

Proposed Mechanism

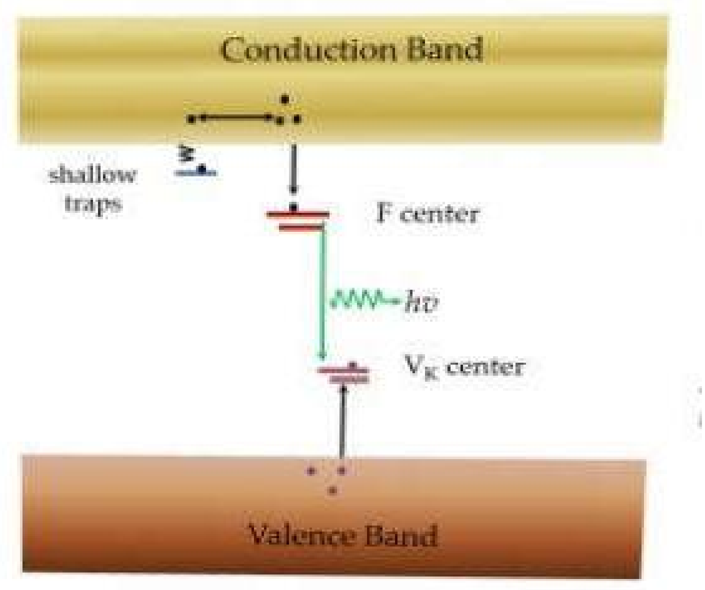
This method is predicted on the hypothesis that the internal electric field that aids in the release of trapped carriers (carrier i.e. electron or hole localized at the lattice defect), which occurs in persistent phosphors or doped semiconductor is caused by piezoelectricity. Piezoelectricity (electric polarization in crystal

Mechanism: Reducing trap method

by applying mechanical stress) can result from intrinsic features of centrosymmetric compound with right kind of microstructure or lattice defect or from non centrosymmetric compound. With the aid of mechanical stress, a decrease in effective energy barrier of trap causes release of more carriers. The fact that anisotropy in elasticity is advantageous in this situation to reduce site symmetry or to generate strong electric field in particular direction. Furthermore if mechanoluminescence results by the means of direct tunnelling between defects and dopants their energy level should be close enough. This technique seems to actually work well for majority of persistent phosphors, if not for all.

Mechanism: Carrier release due to movement of dislocations

F-centres and V-k centres are two types of defect found in alkali halide. F-centre -an electron trapped at anion vacancy and V-k centres – a self trapped hole in deformed alkali halide. Dislocations can bind electrons, excitons, holes through electrostatic and elastic interaction with point defect when they are charged by cations or anions. Mechanoluminescence of coloured cubic alkali halides is now known to be mostly caused by recombination of holes from V-k centres and electrons from F centres. Bending of dislocations brought by internal friction, lower the energy barrier for electrons. Dislocations line move as a whole in crystal during plastic deformation and uses thermal energy for F centres to release electrons. The presence of dislocations induce DIBs band in between band gaps. The energy gap between F centres and DIBs band is due to movement of dislocations or thermal activation energy. In rock salt compounds movement of dislocation is



key component for mechanoluminescence

Mechanoluminescence induced by movement of dislocations (Fig2)

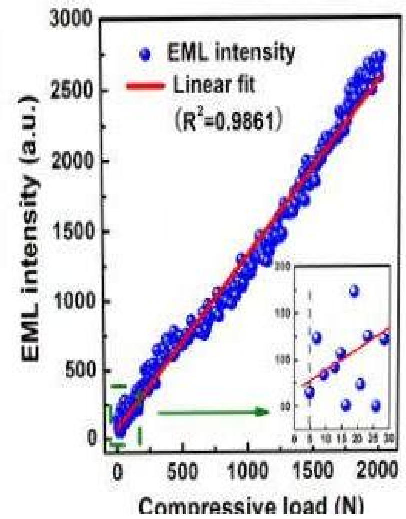
Remarks

For most of materials studied mechanism of mechanoluminescence are not complete. New meachanism and model can arise example triboelectricity generated electroluminescence has been proposed for special mechanoluminescence behavior. However defect plays an important role. The connection between trap densities, trap depth is critical for the mechanoluminescence phenomenon. More carriers trapping defects suggested potentially higher mechanoluminescence property example in ZnS: Cu increase mechanoluminescence by creating vacancies.

However, shallow trap are common thermally eliminated before the start of the mechanoluminescence experiment. Defects like extended and point defects are important in mechanoluminescence phosphors mainly if host is piezoelectric since they can generate large internal electric voltage fields and thus reduce capture barriers. In a prototypical mechanoluminescence experiment, the change in host bandgap is not likely, implying internal electric field caused by defect, play role in charge carrier detrapping. The depletion in detrapping can be attain by changing the composition of defect and it is easily mouldable that even small order of magnitude of stress lead to noticeable shift in detrapping barriers. This probably explains the reason behind mechanoluminescence mostly found in compounds with bendable groundwork. In addition, advanced defect say domain walls and dislocations that activate changes of electronic composition of mechanoluminescence phosphors that lean to the movement under precise mechanical load. The modeling of advancement of mechanoluminescence on different time scale is also crucial for motive of comparing stimulus with on going experiments. Thermodynamics can be the reason behind irreversible nature of mechanoluminescence phenomenon.

Study for CaZr(PO4)2:Eu2+

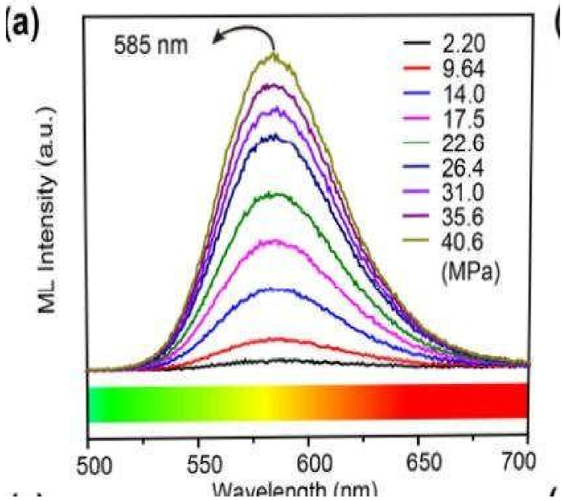
Relationship between CaZr(PO4)2:Eu2+ elastico mechanoluminescence intensity and compressive load. When compressive force increased, elasticoluminescence increases linearly in response exhibiting a typical characteristics that is helpful for understanding the intensity and distribution of stress.



(Fig.3)Mechanoluminescence intensity graph for different compressive load

For ZnS:Mn

Mechanoluminescence performance for ZnS: Mn evaluated using various pressures on object. Figure below show shows how mechanoluminescence intensity grew with applied force.



(Fig.4)Mechanoluminescence spectra under different applied forces

Possible Applications

Under different types of mechanical loads say stress, mechanoluminescent material can emit light. Thus a wide range of application is possible for those materials in pressure mapping, stress measurement, light sources and other fields. Determination of magnetic field and electric field is also possible. The primary functionality of these sensors depends on the properties in particular the sensitivity, the self recovery effect and strain luminescence of mechanoluminescence process. The ideal indicator of mechanoluminescence when looking stress distribution is tiny threshold and high linearity of phosphors. When voltage threshold is low, high linearity between mechanoluminescence and stress supply wide range of mapping to low level of stress. A high sensitivity is also sought since the contrast for various types of stress is crucial for stress mapping. For situations when there is a localized concentration of stress, it is also necessary to know, the maximum stress at which linearity holds.

Recent potential applications

Visualization of stress distribution

When researching recurrent loading of real components or in the design stage of structural components, tracking overall stress of a component under performance is incredibly useful. When compared to electric strain gauges or fibre based strain gauges, mechanoluminescent phosphors offer an alternative option for other sensor matter due to their stretchability and ease of adjustment. This is based on reason that stress is linearly connected to mechanoluminescence intensity. As long as gathering mechanoluminescence intensity is practical and approachable, which is crucial in situations where there is localized concentration of stress, these mechanoluminescent material can be induced into translucent matrix, painted on surface of desired items.

Mechanism in fracture

In the fracture mechanism stress condition near tip of the crack tip is predicted by a remote load using Stress Intensity Factor. One of the modes say pure opening mode, crack surface separates immediately and assume Ki stands for Stress Intensity Factor. Since mechanoluminescence intensity was considered as stress distribution derived from elasticity relations hence we can calculate Ki. The computed Ki correlates well with the values obtained using technique suggested where we are assuming that the stress drift is to reason behind the mechanoluminescence. Similar to this, Stress Intensity Factor can even be determined from mechanoluminescence intensity that has collected in the plastic field near a crack. It broadens mechanoluminescence to induced sophisticated non linear plasticity under intricate loading scenarios

Visualization of ultrasonic field

The pressure that ultrasound creates at wavefront (set of points in space reached by a wave at the same instant as waves travel through medium) of the sound waves can cause some mechanoluminescence material to glow when stimulated with ultrasound. Mechanoluminescence caused by ultrasonic radiation is capable of acting as light source in photo catalyst. However ability to clearly see the pressure field created by ultrasonic wave with aid of some specific compound, it can release light that is inversely proportional to the transducer's output to the power of ultrasound. The use of an epoxy plate placed in various positions in relation to transducer in order to detect pressure by the means of light emission induced by ultrasound. Mechanoluminescence intensities were first captured by a camera and the data afterwards digitally recovered to show pressure distribution at appropriate distances. This distribution was contrast to that acquired by direct scanning with the help of hydrophone, there is a strong link between two techniques and stimulation support the arguments. Consequently it is feasible for researchers to fast and effective reconstruction of 3-d ultrasonic field using mechanoluminescence materials

Design consideration for mechanoluminescence phosphors

Due to wide variety of stress and strain, sensing stress field may be creating interest from a practical standpoint. The use of mechanoluminescence phosphors in stress sensing depends more on their behavior than on a detailed understanding release process of carriers. By alloying anions and cations, codoping or adjusting the syntheses parameters of existing mechanoluminescence phosphors, it is possible to increase the desired calibre of qualities example high range of linearity, efficiency, sensitivity. To find novel host and dopants combinations in practice we need to research on working knowledge of mechanoluminescence process as well as some creativity but they do have several possibilities. Finding new host may be easier if we search for derivatives of established mechanoluminescence hosts.

Compounds with layers or flexible structures which also exhibit persistent luminescence (as in case of majority of mechanoluminescence hosts) allow for a significant change in defects for mechanoluminescence. Due to presence of diverse type of microstructure created during phase transitions, particularly martensic phase transitions might favour strong mechanoluminescence. With the use of these factors, researchers can draught their own mechanoluminescence hosts candidates and test them using metal impurity doping. Unexpected results are also beneficial for investigation of mechanoluminescence mechanism. We can anticipate the use of mechanoluminescence in other disciplines example bio imaging employing ultrasound and usable devices for safety signaling, with better mechanoluminescence phosphors and knowledge of mechanoluminescence mechanism.

Conclusions

Despite the mechanoluminescence's significant application potential, it remains challenging to comprehend its process and create new mechanoluminescence material. A comprehensive examination of crystal framework for mechanoluminescence phosphors reveals the complexity brought on by the co-existence of certain form of microstructure such as modulations, domains, twins and chemical bonding that is anisotropic. As a result the criteria for finding mechanoluminescence candidates are more intricate than simply recognizing piezoelectric phosphor. There are also very few options for tuning the emission wavelength. For instance, mechanoluminescence phosphors emitting near infra red region, might be useful in biological imaging employing ultrasonic radiation, are severely lacking in the market. Depending on particular material under research, difficulties arise from complicated interaction of microstructure and anionic frameworks. Even for most extensively researched mechanoluminescence material, it is unclear how dopant energy level fluctuates in response to stress. The acknowledgement of hysteresis of mechanoluminescence itself is a significant advancement in the mechanoluminescence mechanism. The pertinent model is successful in explaining not only instantaneous mechanoluminescence intensity, under various conditions but also the existence of mechanoluminescence peak on releasing sudden mechanical load.

References

[1] L. M. Sweeting, "Triboluminescence with and without Air," *Chem. Mater.*, vol. 13, no. 3, pp. 854–870, 2001.

[2] L. Chen, M. C. Wong, G. Bai, W. Jie, and J. Hao, "White and green light emissions of flexible polymer composites under electric field and multiple strains," *Nano Energy*, vol. 14, pp. 372–381, May 2015.

[3] X. Wang *et al.*, "Dynamic Pressure Mapping of Personalized Handwriting by a Flexible Sensor Matrix Based on the Mechanoluminescence Process," *Adv. Mater.*, vol. 27, no. 14, pp. 2324–2331, Apr. 2015.

[4] S. Krishnan, H. Van der Walt, V. Venkatesh, and V. B. Sundaresan, "Dynamic characterization of elastico-mechanoluminescence towards structural health monitoring:," *https://doi.org/10.1177/1045389X17689939*, vol. 28, no. 17, pp. 2458–2464, Feb. 2017.

[5] A. Feng and P. F. Smet, "A Review of Mechanoluminescence in Inorganic Solids: Compounds, Mechanisms, Models and Applications," *Materials (Basel).*, vol. 11, no. 4, p. 484, Mar. 2018.

[6] J.-C. Zhang *et al.*, "Elastico-mechanoluminescence in $CaZr(PO_4)_2:Eu^{2+}$ with multiple trap levels," *Opt. Express, Vol. 21, Issue 11, pp. 13699-13709*, vol. 21, no. 11, pp. 13699–13709, Jun. 2013.

[7] X. Wang, R. Ling, Y. Zhang, M. Que, Y. Peng, and C. Pan, "Oxygen-assisted preparation of mechanoluminescent ZnS:Mn for dynamic pressure mapping," *Nano Res. 2018 114*, vol. 11, no. 4, pp. 1967–1976, Mar. 2018.

[8] J. S. Kim, Y. N. Kwon, N. Shin, and K. S. Sohn, "Mechanoluminescent SrAl2O4:Eu,Dy phosphor for use in visualization of quasidynamic crack propagation," *Appl. Phys. Lett.*, vol. 90, no. 24, p. 241916, Jun. 2007.

[9] W. Wang *et al.*, "Ultrasound triggered organic mechanoluminescence materials," *Adv. Drug Deliv. Rev.*, vol. 186, Jul. 2022.