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Persistent luminescence: An insight

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ABSTRACT

Leading to advancement in technological manifestations the phenomenon of persistent luminescence and growth of luminescent materials has witnessed a rapid headway in research and development. It is an optical phenomenon, also referred as long lasting phosphorescence and is applied effectively in safety indications, emergency lighting, graphic arts, interior decoration, multidimensional optical memory and detection of high energy UV, X-rays and β rays. Persistent luminescence is the underlying mechanism that constitutes one of the aspects of solid state lighting technology. LED light bulbs are extremely energy efficient and sustainable since the power consumption is brought down by 80% when compared to conventional light bulbs. Such low energy consumption can save millions in energy costs and can provide eco-friendly sustainable lighting worldwide. Since sustainable energy services are central to economic development, pioneered use of LED lighting powered by renewable energy will cause positive impact not only on environment through reduced carbon dioxide emission and less deforestation but will also provide a cheaper source of lighting to people. The paper highlights the principle working of persistent phenomenon through various models. It also explores the advancement made in this arena through various research input. We are working with the probability of generation of reliable, compact and efficient LEDs with a couple of phosphor systems. Nevertheless, sustainability is multi-faceted. Though LED lighting is worth significant from energy consumption standpoint it is struggling with respect to finite material usage and recyclability. Constant efforts are raised to overcome these shortcomings.

Contents

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1. Introduction

Persistent luminescence has aroused a great zeal and enthusiasm among the researchers worldwide owing to their promising potential applications and remarkable versatile functionality. A higher emission lifetime without an impulse of constant energy input allows several opportunities for persistent luminescent materials not only in optoelectronics but also in fields as diverse as biomedical sciences and energy conserving devices. $^5D_0$-^7F_J $4f_6$ redline emissions of Eu^{3+} and the blue to red 5d–4f emission of Eu^{2+} are both used in display and lighting phosphors [1]. The $4f_8$ line emission of Tb^{3+} is often responsible for the green component in tricolor tube lighting. Dy^{3+} plays an important role in the persistent luminescence phosphor $SrAl_2O_4$: Eu^{2+}, Dy^{3+} [2,3]. Persistent luminescence is a process where the material emits light in the visible range appreciably for hours even after the irradiation source has been waived off. The storage of the irradiation energy by the traps is supposed to be responsible for long decay time of persistence luminescence. It is the most recent rare earth application based on lattice defects. Trivalent rare earth ions fairly influence the duration and intensity of persistent luminescence. As the result of very slow thermal loss of the excitation energy from the lattice defects acting as traps, the new generation persistent luminescent material yield luminescence still visible to naked eye for several hours. The concept of long lasting afterglow is known to mankind a long way back. But understanding of a few intricate mechanical concepts has been put forth by eminent researchers just in the past couple of decades. Still there are certain fundamentals to be resolved. Despite of an ambiguity on the precise mechanism governing the persistent property in luminescent materials, the researchers all around have unanimously agreed on some principles that could be held responsible as amongst the probable mechanisms of the proposed phenomenon. Prior to investigations on different perspectives of persistence it is highly essential to acknowledge comprehensively the term 'phosphorescence' or 'persistent'. Luminescence is classically defined as relaxation of species from the excited state followed by spontaneous light emission. The material is activated or charged by blue/UV content of solar radiation during regular condition. In extreme dark conditions, the energy is released as afterglow. Since the operation is entirely passive no power supply is required as well as a high degree of reliability is assured. On the basis of mechanism, it is straightened out into fluorescence and phosphorescence. Fluorescence is put up with spin allowed radiative transitions from singlet state to ground state. On the contrary, emission between a triplet excited state and a singlet ground state or between any two energy levels that differ in their respective spin states, is known as phosphorescence [4]. The spin forbidden characteristic is regarded as the major cause behind long lived emission in phosphorescence which is often termed as persistence. The researchers contemplate trapping and de trapping of electrons or holes in traps as one of the basic mechanisms of long lasting phosphorescence. As far as trapping is concerned, an electron subjected to the emission center gets excited on irradiation with light photon. By following precise mechanism the electrons are transferred into an electron trap. This electron transfer is associated with electron delocalization. Generally, electron delocalization occurs when the energy level of the excited state of electron overlap with the host conduction band. This phenomenon is often referred as photo-ionization. Delocalization is apparently observed at p and d orbital respectively. Therefore the substantial persistent luminescence from rare earth group is achieved by raising the electrons to 5d excited state through irradiation with UV and VUV photons. No evidence has been found of delocalization occurring at f orbital in spite of having energy higher than 5d orbital. Apart from electron delocalization electron tunneling is also proposed as a way to generate trapped electrons [5]. In this process, the electron trap levels lie near the excited energy levels facilitating the electrons to tunnel into electron traps. These tunneling traps are also known as local traps and are usually defect levels or F centers. Significantly, in case of traps associated with electron delocalization the traps are assigned far away from the emission centers since the electrons are capable to travel through the conduction band for a relative long distance. Such traps are often regarded as distant traps [6].

Long decay period in persistent phosphors can be attributed to traps with different suitable trapping depth. The trapping depth can be defined as the energy responsible to release the electrons from the trap. This phenomenon is called de trapping where the trap depth can be varied from several tenth of an eV to a high range of eV. The de trapping rate A is in close relation with temperature and is given by $A=se^{-E/KT}$ where s stands for the frequency factor for electron de trapping. E is the trap depth and T is the temperature. The s factor counts the numbers an electron interact with a phonon per second at the trap level. The electrons are also susceptible to re trapping in which there a possibility of electron falling back to the trap. Apart from electron delocalization and electron tunneling process, photo de trapping is another tool suggested stimulating electron emission from traps suitably known as photo stimulated emission [7,8]. However; precise discernment in order to appreciate the persistent phenomenon in phosphorescence can be achieved by considering the elementary principles of energy and electron transfer mechanisms in phosphorescent phosphors. Hence, the second section deals with various possible mechanisms of energy transfer involved with different defect centers and interactions between them. These are based on the results of systematic investigations carried out on different luminescent properties. The third section highlights the basic charge transfer process. In the forth section the basic theories of energy transfer applicable to the materials of interest are outlined. The fifth section laid special emphasis on trapping properties which are determined in understanding the persistent