Optica Applicata, Vol. XLI, No. 2, 2011

Studies of rejuvenation of electroluminescent thick film structures

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A set of samples of electroluminescent (EL) lamps with ZnS phosphor was fabricated. These samples were degraded in different working conditions. Next, an attempt to rejuvenate these structures by annealing was undertaken. Several parameters of investigated structures were estimated. Then, measurements were performed after fabrication of test samples, their degradation and annealing. The luminance of the test structures as a function of applied voltage frequency was measured. Also, the spectrum of light emission before and after the degradation and rejuvenation processes was investigated.

Keywords: ZnS, AC electroluminescence, electroluminescent (EL) lamps, thick films.

1. Introduction

Copper doped zinc sulphide displays electroluminescent properties. It is used as a phosphor in thick film light emitting structures. Such electroluminescent structures, or EL lamps, are employed as a backlight for liquid crystal displays in portable electronic devices, such as cell phones, notebooks, PDAs, *etc*. EL lamps are also used as a backlight for instrument panels in cars and airplanes. Such structures may be employed as a source of light in nightlights and decorative elements (for example decorations made from electroluminescent wire). In the advertising industry, EL lamps are also put into service in light emitting elements of billboard advertisements [1].

Unfortunately, such structures are prone to degradation and have a limited lifetime. In order to increase the lifetime of EL lamps, we had to investigate how certain factors influence the process of degradation and how this process can be reversed.

2. Thick film EL lamps

Typical EL lamps are fabricated as multilayer thick film structures (Fig. 1). A layer of phosphor, for example copper doped zinc sulfide, is placed in between two layers of

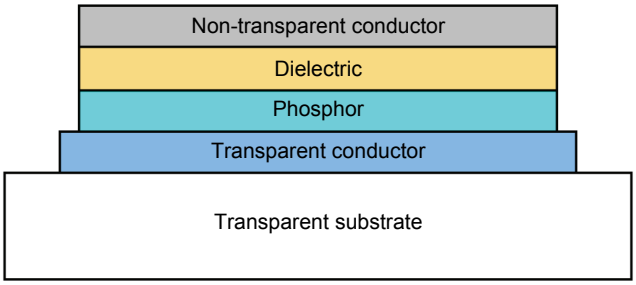

Fig. 1. Cross-section of a thick film electroluminescent lamp.

conductive materials, which makes this structure similar to a simple parallel-plate capacitor. Usually EL lamp structures consist of 4 layers: a layer of transparent conductive material, *e.g.* ITO, a layer of phosphor (Fig. 2), a layer of dielectric and a layer of metallic conductor, *e.g.* silver. The layer of transparent conductor is fabricated on a transparent substrate.

3. Test structures

The test structures were prepared at the Institute of Electron Technology, Division in Cracow. A set of DuPont Luxprint inks, designed to fabricate electroluminescent thick film structures, was utilized to prepare the test structures. A Luxprint 8152B ZnS:Cu based ink was applied to produce an electroluminescent layer on ITO covered transparent polymer substrate. Conductive electrodes were screen printed with the use of silver based ink. Both pastes were cured by drying at 130 °C for 30 minutes in a box oven.

An investigation into the degradation and rejuvenation of thick film EL lamps was undertaken. For this purpose, three sets of test structures were fabricated:

– Set A: used as a reference, with no special treatment after fabrication;

– Set B: a 100 V, 400 Hz square-wave voltage was applied to these structures, for a time span of about 1500 hours. These structures worked in the temperature of 25 °C and humidity of 60%;

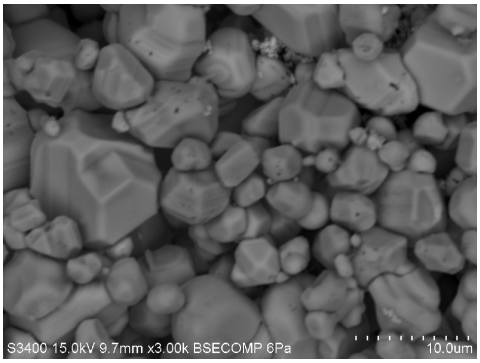

Fig. 2. SEM picture of ZnS:Cu powder, used in fabrication of EL thick-film structures.

– Set C: structures of this set worked in the temperature of 40 °C and humidity of 95% for 300 hours. A 100 V, 400 Hz square-wave voltage was used to drive these structures.

4. Degradation

Several mechanisms of degradation of EL phosphors have been discussed in Ref. [2]. Most often it is suggested that the degradation process involves S vacancy or dopant diffusion in ZnS lattice [3, 4]. Some authors suggest that the mechanism that lowers the efficiency of electron/hole injection may be of importance [5].

A set of measurements of luminance as a function of frequency was performed. These measurements were used to evaluate the influence of degradation on light emission. Also the spectrum of light emission before and after the degradation process was investigated.

In Figure 3 the luminance of samples from the sets A and B as a function of frequency is shown. This characteristic is shown for square-wave excitation of an amplitude of 100 volts. A similar characteristic, for the sets A and C, is also shown in Fig. 3.

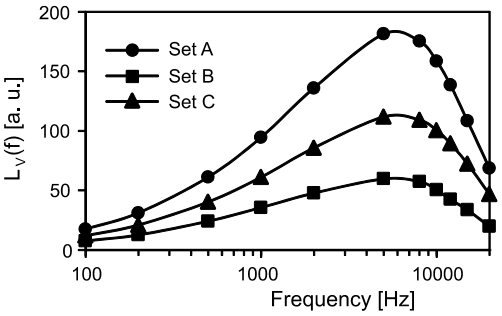

Fig. 3. Luminance as a function of frequency for samples from sets A, B and C, for a 100 V square-wave excitation.

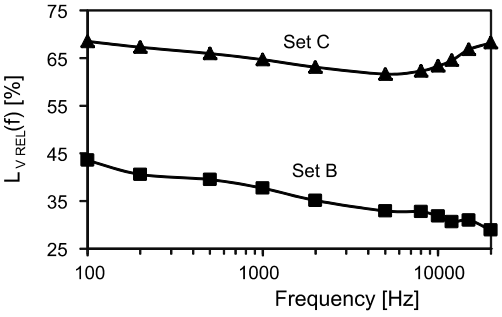

Fig. 4. Luminance of sets B and C of samples, relative to the luminance of set A, as a function of frequency, for a 100 V square-wave excitation.

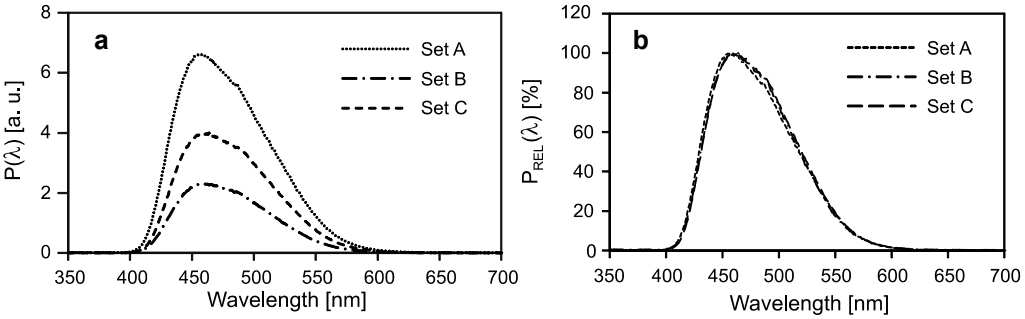

Fig. 5. Spectrum of light emission (**a**) and normalized spectrum of light emission (**b**), for a 100 V, 2 kHz square-wave excitation.

In Figure 4 changes in luminance after the degradation, relative to the reference luminance, are shown. After 1500 hours of work (set B), the luminance of EL structures dropped to 30% from the initial 45%. The higher is the frequency, the stronger are the effects of degradation. In case of degradation (in elevated temperature and humidity (set C) and after 300 hours), the luminance dropped to 60% from the initial 70%. For samples from the set C, the effects of degradation are the strongest for the frequency of 5 kHz.

The spectrum of light emission, before and after the degradation of test structures, is shown in Fig. 5**a**. The process of degradation causes a decrease in light emission. As it is shown in Fig. 5**b**, there are no changes in the shape of the spectrum, therefore this decrease is constant as a function of wavelength.

5. Rejuvenation

Annealing of degraded electroluminescent thick film structures can rejuvenate the ZnS phosphors. An attempt to rejuvenate the test structures was undertaken. It was found that annealing at 130 °C for 2 hours gave the best results. Lower temperatures and

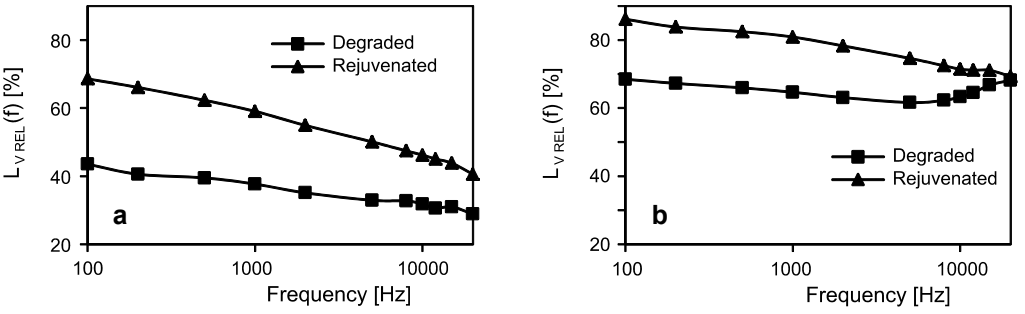

Fig. 6. Luminance of set B (**a**) and set C (**b**) samples, relative to luminance of set A, as a function of frequency, for a 100 V square-wave excitation.

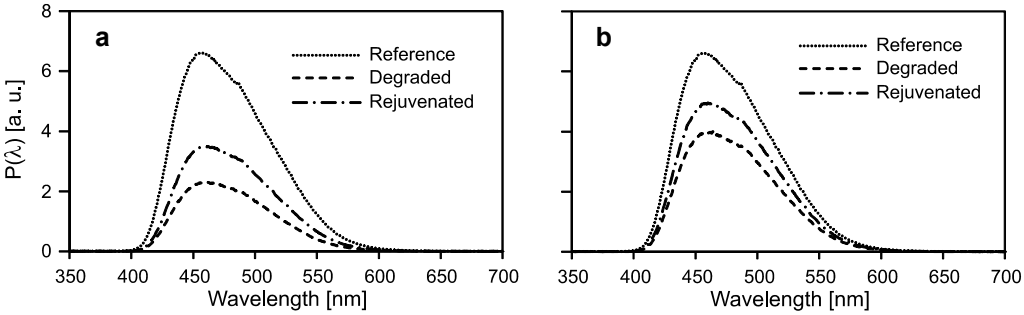

Fig. 7. Spectrum of light emission of set B (**a**) and set C (**b**) samples, for a 100 V, 2 kHz square-wave excitation.

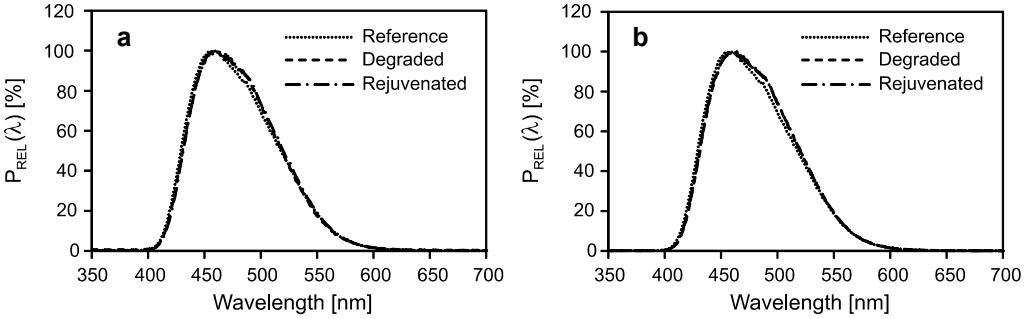

Fig. 8. Normalized spectrum of light emission of set B (**a**) and set C (**b**) samples, for a 100 V, 2 kHz square-wave excitation.

shorter times did not give satisfactory results and temperatures higher than 130 °C damaged the test samples.

For samples from the set B, annealing allowed to increase the luminance from about 45% to 70% of the initial value for the lower frequency of 100 Hz and from 30% to 50% for 20 kHz (Fig. 6**a**). In case of samples from the set C (Fig. 6**b**), the increase was from 70% to 85% for 100 Hz. There was no increase observed for 20 kHz.

Rejuvenation caused an increase in the spectrum of light emission (Fig. 7) but did not change the shape of the spectrum (Fig. 8).

6. Summary

On the basis of the research work performed it can be concluded that:

– Annealing of degraded electroluminescent thick film structures allowed to rejuvenate these structures;

– The increase in luminance of the rejuvenated structures did not reach 100% of the initial value;

– Further research is required to better understand the mechanism of rejuvenation and to investigate whether the multiple cycles of degradation and rejuvenation are possible.

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Received September 25, 2010