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High power LED assemblies for solid state lighting – Thermal analysis

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ABSTRACT

We report on the Chip-on-Plate (COP) packaged high power LED assemblies for solid state lighting (SSL) and backlighting display applications from thermal analysis perspective. Three different light modules with different elements (devices) distribution and heatsink design were considered. Thermal resistance circuit (TRC) model and heat diffusion equation were employed in this study of thermal behavior of the assembly elements. Finite element analysis along with 3D modeling and simulations were used for considered lighting modules and assemblies. Also, the effect of thermal uniformity on the emission spectra was evaluated for different operating powers. Comparative study showed that conventional packages with circularly symmetric having non-uniform devices' distribution per unit area will have temperature differences ~7 °C among the chip-elements operating around 1.25 W power level. Also, it was predicted that high elements temperature difference could result in over 2 nm redshift in the emission spectra accompanied by ~ 4% drop in the output power. However, temperature difference was found to be less than 1 °C for the uniform rectangular array module distribution, which ensures uniform output intensity for all devices. Such findings are extremely useful for designing larger area LED packaging where thermal non-uniformity effects are expected to be more severe for devices' longevity and performance.

1. Introduction

Solid-state light (SSL) sources are playing pivotal role for the design and development of lighting modules for their coherent and non-coherent applications. The low-cost lighting modules continue gaining increased interest worldwide owing to their compactness and environmental friendly nature. Nowadays, SSL sources are preferred for most commercial applications because of their durability, long-lifetimes, low-cost, small size, and their low energy consumption [1,2]. Despite the major advances highlighted above, some of the basic problems continue to hamper their practical applications. As their market demand increases, it becomes imperative that these problems are addressed efficiently. Thermal stability has been one of the most pressing challenges currently faced by SSL devices [3]. It has been found that all the light sources include LEDs and LDs produce heat when biased using power supplies. Heat is mostly generated by Joule-effect due to series electrical resistance of the device epi-structure and non-ideal quantum efficiency. An increasing device (chip) temperature, further causes their quantum efficiency to drop because heat will excite impurities and defects (electron traps) that will result in less radiative recombinations in the junction region, and thus decrease the intensity of the emitted light [4,5]. The typical output of an average LED is about 20%, heating presents a further reduction in the output power and the lifetime of SSL modules built using such point sources [6]. In addition to the reduction of the output power; elevated temperatures affect the energy bands structure of the semiconductor materials, and shrink the energy bandgap which gives rise to longer wavelengths in the emission spectrum. This effect leads to a redshift of the output spectrum [7]. Typically, these point light sources are assembled together in various sizes of arrays depending on their intended application. Some applications use individual devices e.g., short wavelength optical communication. However, solid state lighting, require large assemblies of LEDs to produce similar or yet higher light intensity than conventional light sources [8,9]. Sometime array of these LEDs are integrated together in different assemblies to achieve recommended levels of optical flux densities. However, it becomes critical to incorporate mandatory thermal management for the optimal performance of the design lighting modules in terms of their color temperature, color purity, and color rendering index (CRI). Thermal management is a must to ensure the removal of excess heat from the LED chips into the ambient in order to maintain these chips at an acceptable temperature. This results

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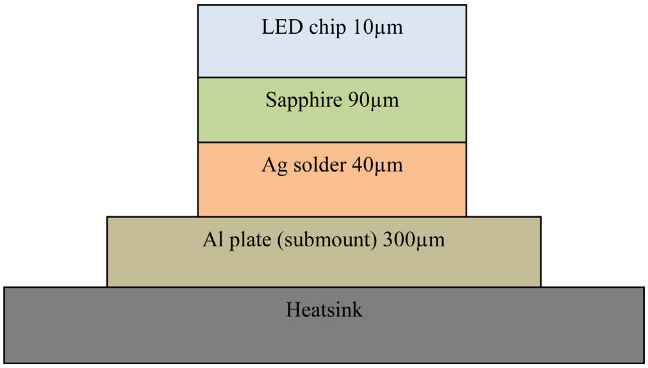

Fig. 1. Cross-sectional view of COP LED package (not to the scale) and typical thicknesses of layers are denoted.

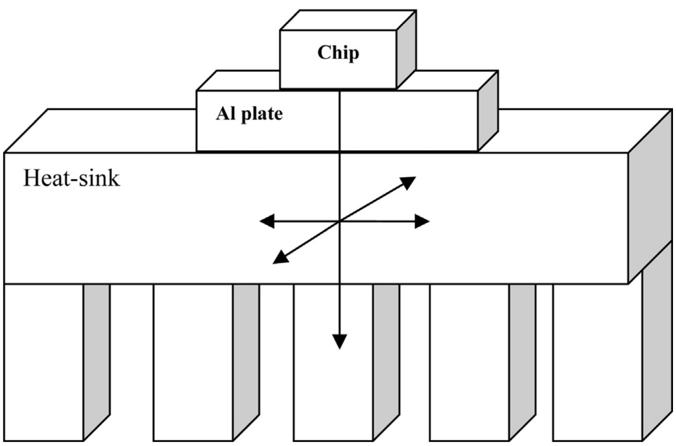

Fig. 2. Thermal paths for one LED assembly element [13].

in steady light output, spectral stability and long lifetime. These improvements would ensure efficient, durable, and low-cost light sources, thus help to decrease the transition time needed to complete the conversion from ordinary light sources to next generation SSL technology [10].

When array type LED assemblies are designed, it is essential that all chips produce nearly similar light output and have the same thermal behavior. We introduce thermal uniformity among various elements of the assembly as a method to evaluate their thermal stability. Generally, thermal uniformity is realized by mapping the overall temperature difference over the entire assembly-elements. This temperature difference would ensure if there was any issue linked with the poor thermal uniformity; where a small difference implies high thermal uniformity.

In this paper, high power LED chips based assemblies have been designed and simulated for their thermal management. Moreover, finite element analysis has also been performed for comparative study of their thermal uniformity in order to enhance the thermal stability that uses specific geometrical distribution of the assembly elements. All assemblies considered in this study use Chip-on-plate (COP) packaged high power AlGaN/GaN based LEDs. COP packaging is one of the most recent technique being exploited for the thermal management of photonic-devices, where high thermal conductivity metal plates are used as submounts. Fig. 1 shows a typical COP package diagram used for each assembly element; a more detailed analysis of the COP package and performance is described elsewhere [11].

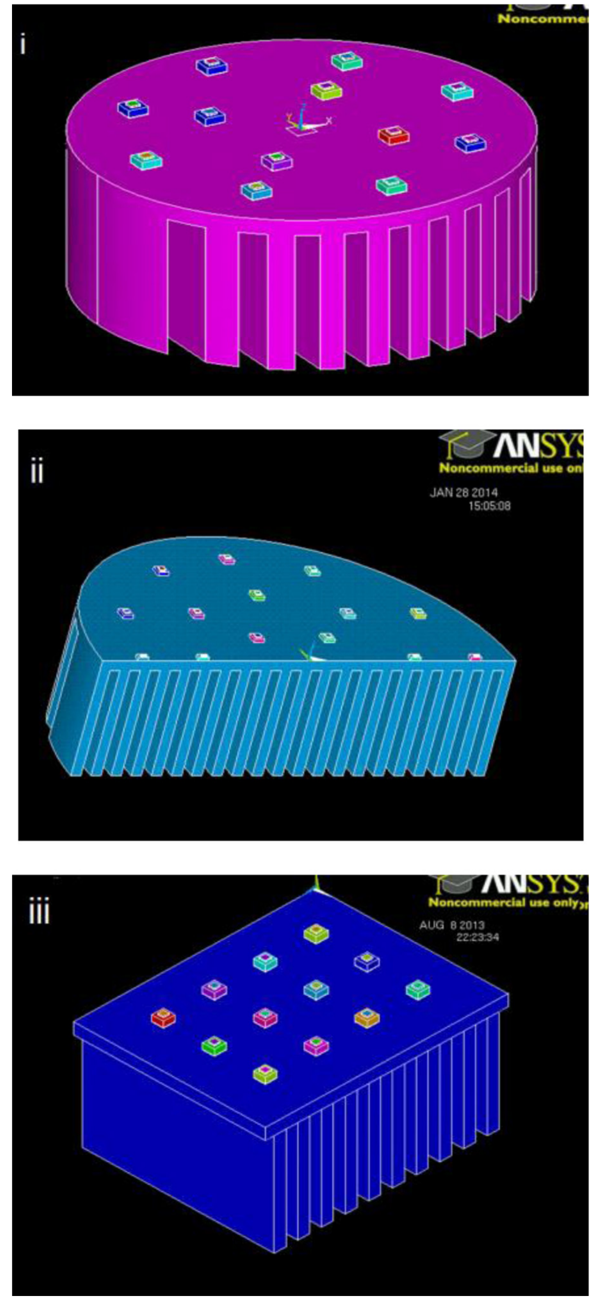

Fig. 3. 3D models of different LED assemblies/modules. (i) Lighting-module (A), (ii) lighting-module (B), and (iii) lighting-module (C).

2. LED assembly's thermal uniformity analysis

As mentioned, multiple assemblies of GaN/AlGaN high-power LEDs chips were modeled. The aim is to study the thermal behavior of these LED chips using Chip-on-Plate technique. In brief, each LED chip is packaged using COP design where each chip is biased individually. Thermal grease is used to fix the COP chips on the heatsink. Standard plate-fin copper heatsinks of 1-cm in length and 1 mm thickness were used. Thermal behavior of individually packaged chips was studied using thermal resistance circuit model (TRC) [12]. As a part of operating power dissipates through LED chips, heat is generated. Heat spreads in the downward direction from the junction layer and dissipates through the heatsink. Thermal paths of each LED chip are shown in Fig. 2. It is evident that the main path is vertical from chip to heatsink; however, it branches