Solid-State Electronics 85 (2013) 1–5

Contents lists available at SciVerse ScienceDirect

Solid-State Electronics

journal homepage: www.elsevier.com/locate/sse

Change of effective thermal resistance of LED package according to an input current level

Peng Fei Ji, Cheol-Hee Moon *

School of Display Engineering, Hoseo University, Asan City 336-795, South Korea

ARTICLE INFO

Article history:
Received 5 December 2011
Received in revised form 14 January 2013
Accepted 29 January 2013
Available online 3 May 2013

The review of this paper was arranged by Dr. Y. Kuk

Keywords:
LED
Effective thermal resistance
Residual thermal resistance
Junction temperature
Optical efficiency
External quantum efficiency (EQE)

ABSTRACT

The effective thermal resistance (R_{the}) of a light-emitting diode (LED) is determined to be the residual thermal resistance (R_{thr}) multiplied by $(1-\eta)$ where η is the optical efficiency. We investigated the change in R_{the} for 24 mil and 35 mil LEDs according to an input current change of up to 700 mA using a transient thermal method with a thermal resistance tester (Metasystem™). Both the 24 mil and 35 mil LEDs showed a bimodal dependency of R_{the} on the input current level. A 35 mil LED showed a smaller R_{the} value and a relatively smaller rate of increase of R_{the} for an input current level over 100 mA. To elucidate these results, R_{thr}, η, and the external quantum efficiency (EQE) were investigated.

1. Introduction

Light-emitting diodes (LEDs) are fast replacing incandescent lamps and are widely applied in areas such as signaling, illumination, narrow band light sensors, and non-visible applications. With their advantages of high efficiency, long life span, flexible fabrication, and environment friendliness, LEDs have become popular in consumer electronics. The common parameters used to evaluate the thermal performance of LEDs are the junction temperature and the thermal resistance. The junction temperature is the temperature located at the active region crystal lattice, which has a significant effect on the thermal characteristics of LEDs. Thermal resistance is also an important performance parameter that indicates the obstruction of the heat flow from the p–n junction to the ambient surroundings during operation. There are two kinds of thermal resistances: R_{thr} and R_{the}.

R_{thr} is the residual thermal resistance. It is determined by the thermal conductivity and dimensions of each component, which consist of the heat dissipation path and heat transfer characteristics of the system. R_{thr} is defined as:

$$R_{thr} = \Delta T / P_{heat} \quad (1)$$

where P_{heat} is the dissipated energy and is defined as $P_{electrical} - P_{optical}$. R_{thr} characterizes the thermal dissipation characteristics of the LED package. R_{the} is the effective thermal resistance, which includes the optical efficiency of the LED chip (η). R_{the} is based on electrical power, which is meaningful from the customer's viewpoint. The two kinds of thermal resistance, R_{thr} and R_{the}, are related as follows:

$$R_{the} = R_{thr}(1-\eta) \quad (2)$$

We assumed that R_{thr} is constant for the same chip size in the range of the input current change considered in this experiment. The main purpose of this study is to elucidate the change in R_{the} in the range of the input current change. R_{the} is defined as:

$$R_{the} = \frac{\Delta T_J}{P_e} = \frac{\Delta T_J}{I_F \cdot V_F} = \frac{T_J - T_A}{I_F \cdot V_F} \quad (3)$$

where ΔT_J is the junction temperature rise, P_e is the given electrical power, I_F is the forward current, V_F is the forward voltage, and T_A is the ambient temperature.

Jayasinghe et al. [1] discussed variations of the thermal resistance coefficient as a result of changes in the power dissipation and ambient temperature by using a steady state measurement to calculate the thermal resistance. They suggested that the increase in thermal resistance as a function of drive current can mostly be attributed to the current crowding phenomenon, and also somewhat to the conductivity changes of the GaN and TIM

* Corresponding author. Tel.: +82 41 540 5923; fax: +82 41 540 5929.
E-mail address: chmoon@hoseo.edu (C.-H. Moon).

0038-1101/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.sse.2013.01.019

materials caused by increased heat. Farkas et al. [2] created a model that explains the thermal resistance changes at different current levels. They proposed that if the effect represented by the serial resistance is in a material section near the junction, the expanding thermal resistance follows the growing power levels. On the other hand, if the effect represented by the resistor is in a material section located far from the junction, both the shrinking and expanding effects on thermal resistance follow the changing power levels. Yang et al. [3] showed that the weight fraction of the internal electrical resistance in the LED structure determines the trend of the thermal behavior with different input currents. They said that with a low weight fraction, the thermal resistance of the LED package would decrease with input power. On the other hand, with a high weight fraction, the thermal resistance would grow when increasing an input power. We investigated the change of the effective thermal resistance R_{the} according to an input current level, and interpreted the results using R_{thr}, η, and the external quantum efficiency (EQE).

2. Experimental

2.1. Experiment preparation

In order to investigate the impact of variable currents on the thermal performance of LEDs, a very simple package without MPCBs was fabricated. As shown in Fig. 1a, the 24 and 35 mil vertical chips were adhered to the ceramic substrate through a die attach, or a thermal interface material that works as a thermally conductive adhesive.

2.2. Transient thermal measurement background

A thermal resistance tester (Metasystem™) was used to measure the thermal resistance of the LED package. The Metasystem uses a three-step sequence to determine the thermal resistance. First, the *K*-factor as a characteristic parameter is calibrated using three successive thermal equilibrium environments (298, 313, and 328 K) with a 1 mA bias current (I_{bias}) based on the following equation:

$$K = \frac{\Delta T_J}{\Delta V_F} \quad (4)$$

where ΔT_J is the change in the LED junction temperature and ΔV_F is the change in the LED forward voltage [4]. Then, after driving the ambient temperature to stably reach a 298 K, input currents of 25, 50, 75, 100, 300, 500, and 700 mA are applied. Finally, using the recorded cooling curve, the corresponding structure function and input power are extracted.

The cooling curve was transformed into a Foster R–C network called a network identification by deconvolution (NID). However, since the Foster network is theoretical, it was transformed into a Cauer network from which the cumulative structure function could be drawn [5,6]. From Fig. 1b, we know that the total thermal resistance (R_{th-J-A}) tested by the transient thermal measurement is composed of the thermal resistance from the junction to the substrate (R_{th-J-S}), and the thermal resistance from the substrate to the ambient conditions (R_{th-S-A}).

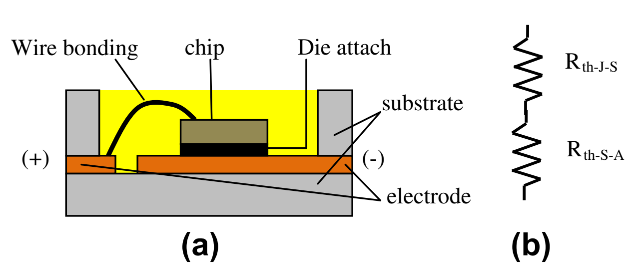

Fig. 1. LED schematic structure and the equivalent thermal circuit. (a) Package structure and (b) equivalent thermal resistance.

3. Results and discussion

In Fig. 2, the *X*-axis interval between the initial point and the terminal point of each plot indicates the thermal resistance from the junction to the ambient conditions (R_{th-J-A}). In this study, R_{th-J-A} is regarded as the effective thermal resistance (R_{the}) used to evaluate the LED's performance.

Fig. 3 shows the junction temperature increase as a function of LED input current for the 24 and 35 mil chips at a 298 K ambient temperature. The junction temperature slope of the 24 mil chip is steeper than that of the 35 mil chip due to the greater heat source density. In Fig. 3, $\Delta T_J = T_J - T_A$. Thus, we note that the junction temperature of the 24 and 35 mil LEDs ranges from 299 to 366 K and 299 to 333 K, respectively. We also note that the junction temperature increased with an increasing input current.

We gathered the results of the thermal resistance from the junction to the ambient conditions for the 24 mil and 35 mil LEDs from Fig. 2, and reorganized these data in order to draw the graph shown in Fig. 4. Fig. 4 shows R_{the} as a function of the input current for the two chip sizes at an ambient temperature of 298 K. Our goal is to elucidate the characteristic changes of R_{the} in the range of the input current change shown in Fig. 4. We can determine three characteristic changes. First, according to the increasing input current, the graphs show bimodal characteristics; that is, R_{the} decreases at low-level currents and increases at high-level currents. Second, the R_{the} value is much higher for the 24 mil LED than for the 35 mil LED. Third, the increasing rate of R_{the} in the range over 100 mA is higher for the 24 mil LED than for the 35 mil LED. We investigated the following three issues.

3.1. The bimodal characteristics of the R_{the} according to an input current

We made the assumption that R_{thr} is constant for the same chip size in the range of the input current change considered in this experiment. The maximum increase in junction temperature is 70 °C as shown in Fig. 3, which is considered to have a negligible effect on the thermal conductivity of the materials [7]. As shown by Eq. (2), R_{the} is defined as R_{thr} multiplied by $(1 - \eta)$ as below:

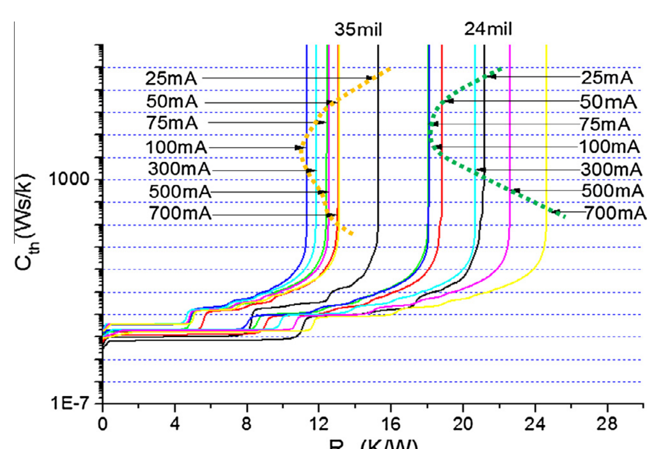

Fig. 2. Cumulative structure function for the 24 and 35 mil LEDs using variable input currents.