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Optical role of die attach adhesive for white LED emitters: light output enhancement without chip-level reflectors

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Abstract

A thin optical reflector is often introduced to the backside of the standard mesa type light emitting diode (LED) chip with the aim to enhance its light output. However, most of the reported light output enhancements because of backside reflector (BR) introduction might not be relevant. This is because the reported measurement is often from a naked LED chip instead of a packaged LED emitter, and those based on the packaged emitters employing conventional silver based die attach adhesive (DAA). The actual role of BR, which is expected to be greatly influenced by the packaging materials and processes, is investigated for the monotonic blue color and white LED emitters using Monte-Carlo simulations. Contrary to prior reports, it is demonstrated for the first time that the role of BR can be diminished when the optically transparent DAA is used and other key packaging materials and processes are optimized, i.e., the light output for a packaged emitter with a BR-free chip can be as high as that of the packaged emitter using the same chip but with an added BR.

Keywords: Light emitting diode, Backside chip reflector, Die attach adhesive

Background

The Gallium nitride (GaN) based mid-power (input current less than 350 mA and input power less than 0.8 W) mesa type light emitting diodes (LEDs) dominate the current LED lighting and backlighting applications because of their cost effectiveness as well as relatively high performance [1–3]. For those LEDs, various types of chip-level backside reflectors (BRs) with a reflectance as high as of 98 % have been developed for adding on their backside, with an aim of enhancing its light output. An enhancement of as high as of 50 % is reported [4–6]. Because of those results, the chip level BR is now often adopted as a part of mesa-LED chip structure. However, the reported enhancement measurements based on the naked chip [4, 5] might not be relevant to practical applications: Firstly, an enhancement from a naked chip does not necessarily lead to an equivalent enhancement for a packaged LED emitter. This is because light output of the LED emitter is strongly influenced by packaging materials and process [7, 8]. Secondly, not every BR achieves the highest reflectivity, but Au-based reflective layer has been typically used for low cost LED chips despite relatively lower reflectivity at the wavelength shorter than 550 nm. The introduction of BRs is also historically related to the conventional silver-based die attach adhesive (DAA) which is optically absorptive and thus a highly optically reflective BR can reduce the absorption of downward photoemission from the multiple quantum well (MQW). Over last few years, however, an optically clear DAA (CDAA) has been introduced, which can have significant impact on the role of BRs for mesa type LEDs [9].

Hence, the objective of the present work is to investigate light output difference from a packaged LED emitter using a BR-free and BR-based chip as a function of packaging materials and processes, by using Monte Carlo simulations. Contrary to prior reports based on naked chips, it is demonstrated for the first time that the light output of a packaged LED emitter with a BR-free chip can indeed be as high as that of the emitter using the same chip but with an added backside reflector when the optically clear DAA replacing conventional silver type DAA and a few other key packaging materials and processes are optimized.

Method

A schematic cross-sectional drawing of a packaged blue LED emitter is shown in Fig. 1(a), and the corresponding optical model for the Monte Carlo simulation using *LightTools* is illustrated in Fig. 1(b). The thickness of each layer and its respective relative refractive index [5] can be found in Fig. 1(c). For the optical simulation, 2 million rays are traced and the simulation error to be maintained less than 1 % for each simulation run. An input current of 120 mA is used and the chip (24 × 24 mil in size) has a dominant wavelength of 450 nm. Absorption coefficients for the GaN and the MQW are 200 cm-1 and 3600 cm-1, respectively [10, 11]. For the BR-based chip, commercially available LED chips with two different BR materials are selected: the BR with the

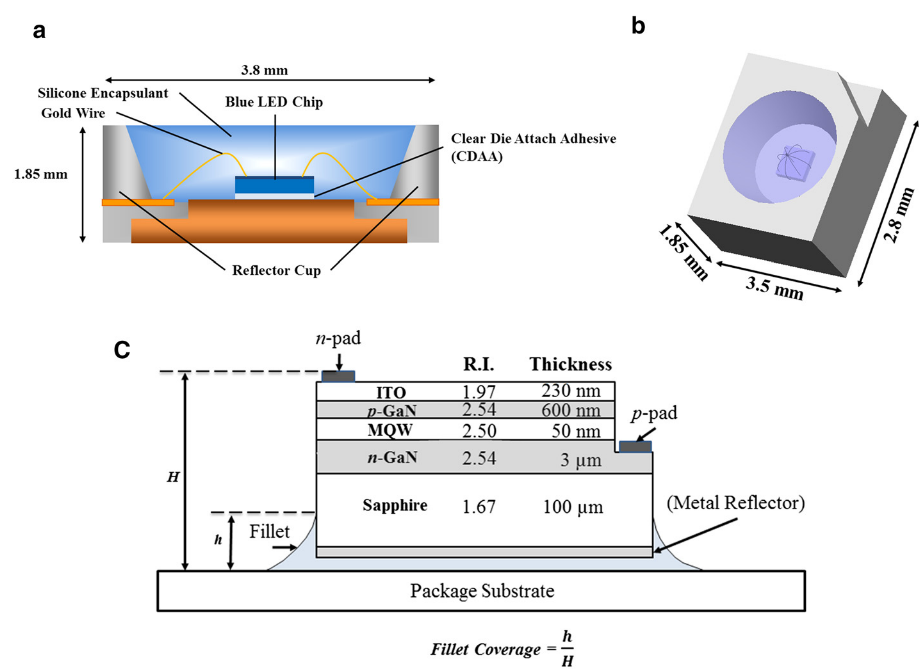

Fig. 1 Leadframe based LED emitter; (**a**) Schematic cross section of a packaged LED emitter by using optically clear die attach adhesive (CDAA), (**b**) optical model used in Monte-Carlo simulations and (**c**) microscopic enlargement of the blue LED chip attached on the leadframe substrate by using CDAA. Layers are not plotted in their relative thickness in order to present illustration. The size of the chip is 24 × 24 mil (0.61 × 0.61 mm) and the thickness is about 100 μm

reflectivity of 98 % at 450 nm by consisting of 3-layers of DBR (Distributed Bragg Reflector) and Ag plating, and the Au-based BR [12]. Due to the metal plating for each BR, the transmission through the BR is not considered and therefore the light output which is not reflected at the interface is absorbed during the simulations. The package has the dimension of $3.5 \times 2.8 \times 1.85$ mm, the depth of the diffusively reflective cup (with a reflectance of 95 %) is 0.9 mm, and its upper and lower diameters are 2.4 mm and 1.75 mm, respectively. The reflectance for the leadframe substrate (R_{LF}) ranges from 80 % to 99 % [13]. For the experimental samples, three groups of leadframe substrates with different reflectance are employed. The measured reflectance for each group is presented in Table 1. The silicone encapsulant has a relative refractive index of 1.53, and the optical transmittance for 1 mm in thickness is 99 %, all at the wavelength of 450 nm [14]. For WLED emitters used in this work, 7.5 wt. % of yellow phosphor powder with dominant peak wavelength of 535 nm is distributed by mixing with the encapsulant [15] and resulted correlated color temperature (CCT) is 9,000 K.

Two types of DAA materials are used for die bonding. One is an optically clear DAA (CDAA) formulated by Shi group [16] and the other is commercially available conventional silver-epoxy based DAA (denoted as AgDAA). For the CDAA, optical transmittance is set of 85 % for 1 mm in thickness, and the relative refractive index is ranging from 1.42 to 1.78. For the packaging parameters of the CDAA, the range of the bondline thickness is from 5 μm to 25 μm [17]. The fillet coverage by CDAA is set up to 40 % of the chip height for the experimental measurement.

The junction temperature which affects luminous efficiency for the LED emitter is proportional to input current, thus thermal management in high-power LEDs has been widely considered [7, 18]. However, the possible thermal-radiation coupling is not considered in the simulations because relatively lower power is involved in the present case of mid-power LEDs [19].

The packaging process for experimental measurement is as follows: (1) the leadframe with same dimensions described above is cleaned by isopropyl alcohol and baked at 80 °C before used; (2) a blue LED chip is attached to the center of the leadframe substrate by using CDAA, and different bonding forces are applied to obtain different bondline thickness; (3) the samples are then cured at 150 °C for 2 h; (4) wire-bonding is performed for interconnect between the LED chip and the leadframe; (5) silicone encapsulant is injected into the reflective cup; (6) the samples then are cured at 150 °C for 2 h; (7) The packaged LED emitters are then soldered to Al-based printed circuit board (PCB). Everfine power generator with constant current mode of 120 mA is used. Light output of packaged LED emitters is measured in a LabSphere integrating sphere.

For the verification of the current simulations, the simulated results for the light output as a function of BR reflectance (R_{BR}) for the naked monotonic blue color emitting LED chip, are compared with the available experimental data [5]. As shown in Fig. 2, it is evident the simulation is fully supported by the experimental observation, which provides the tangential support for the simulation method adopted in the present

Table 1 Reflectance for leadframe substrates

Index	A	B	C
Reflectance[a] (%)	82.1	88.2	94.2

[a]Reflectance at the wavelength of 450 nm

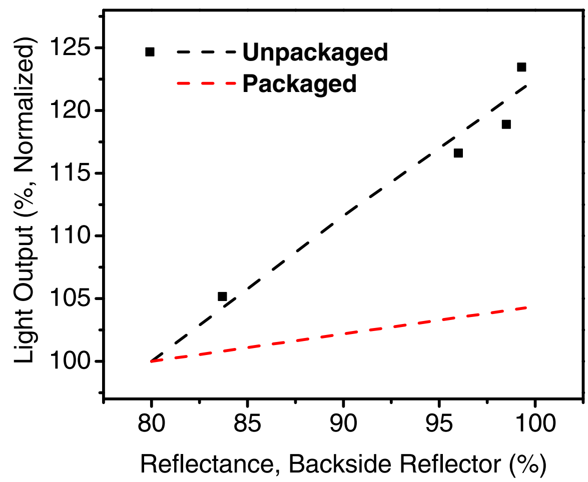

Fig. 2 Naked chip vs. Packaged emitter; Light output for unpackaged naked blue LEDs and packaged blue LED emitters as a function of reflectance for the backside reflector (R_{BR})

work. It is interesting to note a strong difference between the naked LED chip and packaged LED emitter in terms of the light **o**ut dependence on R_{BR}: Due to the influence by the packaging materials and parameters, the enhancement by the BR in light output of the packaged emitter is not as much as for the naked chip, which suggests a possible diminished role of BR in enhancing the light output for a packaged emitter, demonstrated as follows.

The light output of packaged LED emitter as a function of fillet coverage is also shown in Fig. 3. Due to much lower photo absorption by the CDAA compared to the conventional AgDAA, the light output is not reduced up to 40 % of CDAA fillet coverage. The comparison of light output between BR-based and BR-free LED emitter is done by using CDAA.

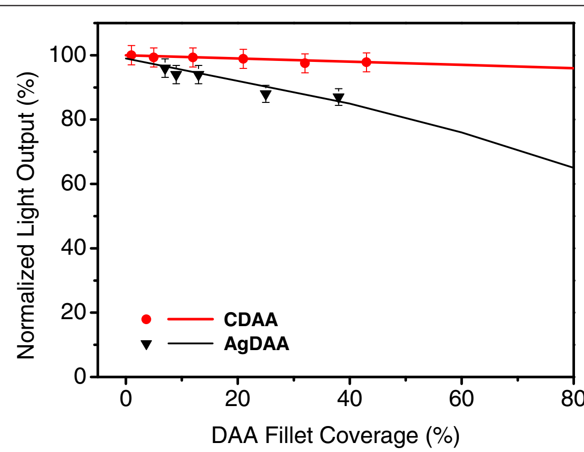

Fig. 3 CDAA vs. AgDAA; Light output of blue LED emitters encapsulated with silicone encapsulant as a function of DAA fillet coverage. The Optically clear DAA is denoted as CDAA and the conventional DAA with silver paste is denoted as AgDAA. Error estimated for the simulation is 0.944 %

Results and discussion

A. Light Output of Packaged LED Emitters vs Reflectance of Leadframe Substrate

Figure 4 presents the light output of blue and white LED emitters as a function of the reflectance of leadframe substrate, R_{LF}. The bondline thickness of the CDAA is 5 μm, which is typical in applications. The results show that BR-free emitter exhibits much higher light output than Au-BR based emitter while the BR-based emitter with R_{BR} is 98 % as an extreme case shows the highest light output. Note that current BR materials used in industry are still Au-based in general, especially for mid-power and low-cost chips. Due to the absorption of Au based BR for the wavelength of shorter than 550 nm [12], light output for the Au BR based emitter is much lower than BR-free emitters performed in both simulations and experimental measurements. Although the role of the BR with R_{BR} of 98 % which contributes to the light output enhancement can be still found, the enhancement due to the BR for the BR-based blue LED and WLED emitters diminish to only 6 % and 7 %, respectively. It is much weaker than the reported naked chip level enhancement, and even more diminished when the R_{LF} is getting increased. Unlike the conventional LED packaging by using silver based DAA, substantial amount of photo absorption by the DAA can be avoided by adopting CDAA. Thus the BR might not be necessary when the R_{LF} reaches to an optimized reflectance due to the diminished role of the BR at relatively higher R_{LF}. In addition, a removal of the BR allows LED chips having much simpler structure than BR-based chips. This approach may lead to a cost reduction of about 5 to 10 % for chip fabrication not only by reduced number of process and materials, but also by improved uniformity in optical characteristics due to those simple structure and fabrication process. Hence, LED emitters with simple BR-free chips may further improve performance to cost ratio for manufacturing LED applications.

The light output for the BR-free emitter is more dependent on the R_{LF} than the BR-based emitter because the portion of reflected photons by leadframe substrate is greater due to optically transparent interface between the LED chip and CDAA. Hence, it is evident that the R_{LF} is a dominant parameter to obtain higher light output, and therefore higher reflectance for the leadframe substrate is preferred for enhancing optical performance of LED emitters.

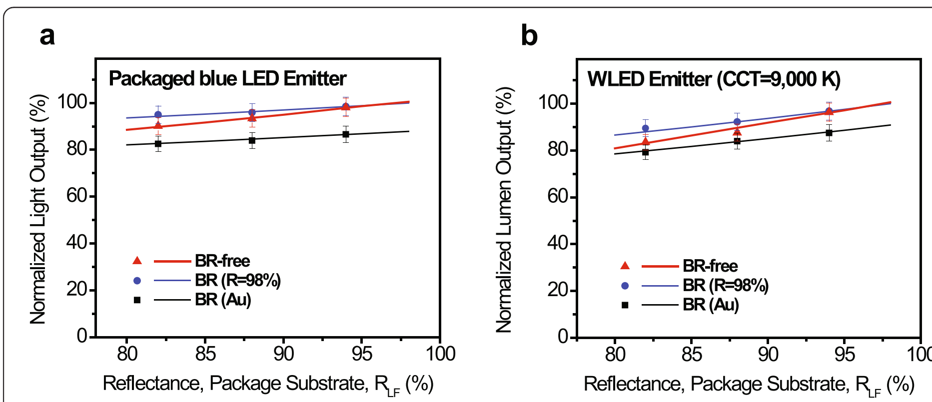

Fig. 4 Light output of BR-free emitters; Light output of (**a**) a blue LED and (**b**) a white LED emitters with BR-based and BR-free chip as a function of reflectance of the leadframe substrate (R_{LF}). Bondline thickness of the CDAA is 5 μm. Results are normalized by the light output of BR (R_{BR} = 98 %) based emitter at R_{LF} of 98 %. Error estimated for the simulation is 0.814 %

B. Light Output of Packaged LED Emitters vs Thickness of CDAA

The light output of blue LED emitters and WLED emitters as a function of CDAA bondline thickness are shown in Fig. 5. A light output enhancement is observed in case of a BR-free emitter, by optimized refractive index of 1.53 for the CDAA, as shown in Fig. 5(a). The results show that increased bondline thickness from 5 μm to 25 μm further enhances light output for the BR-free emitters up to 2 % while the BR-based emitters maintain the difference of the light output within 0.1 %. The light output for the Au-BR based emitter is still much lower than BR-free emitters due to the absorption less than 550 nm. Figure 5(b) presents the luminous output of white LED emitters by using CDAA with the refractive index of 1.53. The light output of the BR-free emitter is more enhanced by increased bondline thickness of the CDAA for both blue and white LEDs.

The R_{LF} is a dominant parameter for a BR-free emitter to enhance light output as we discussed above. And the optimization of optical properties and process parameters for the CDAA besides the R_{LF} would be also an important factor due to the reasons as follows: Firstly, a higher reflectance may require surface treatment on the leadframe substrate [20], which causes an increase in manufacturing cost. Secondly, it is still challenging that the leadframe substrate obtains such higher reflectance because there exists an upper limit of reflectance for the metal plating in practical applications [21]. An enhancement in light output for the BR-free emitter is observed by using an optimized relative refractive index of 1.53 for the CDAA, which is a matched refractive index with the encapsulant. This allows a part of downward photoemission reflected by the leadframe substrate not being trapped by CDAA and reabsorbed by GaN-based active layers, but being extracted towards encapsulation region through the interface between CDAA and encapsulant, and thus contributes to enhancement in light output. That interface is more expanded by increased bondline thickness, and therefore the light output for the BR-free emitter is much further enhanced with relatively low R_{LF} with respect to the BR with the R_{BR} of 98 %. The enhancement of 2 % by optimized process parameters for the CDAA is within the

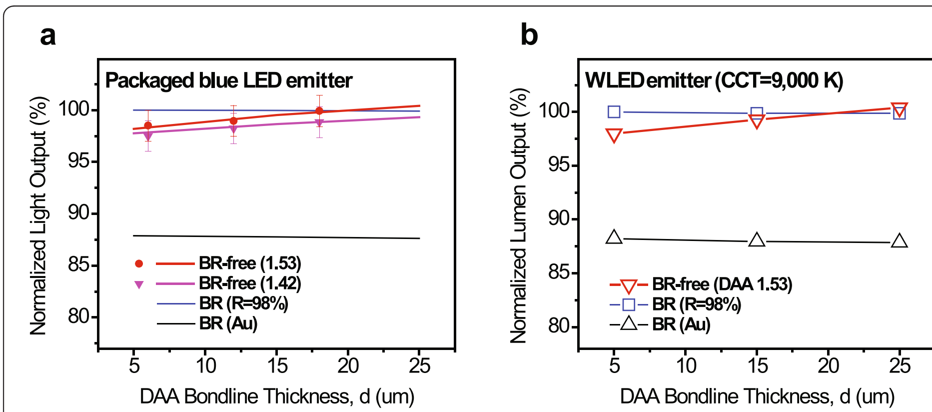

Fig. 5 Light output by CDAA; Light output of (**a**) blue LED emitters with different refractive indices for CDAA and (**b**) simulation of the white LED emitter as a function of CDAA bondline thickness, d. Reflectance for the leadframe substrate (R_{LF}) is 88.2 %. Results are normalized by the light output of BR (R_{BR} = 98 %) based emitter at d of 5 μm. Error estimated for the simulation is 0.917 %

experimental error. However, the tendency of light output enhancement has shown that the simulation results are remarkable.

In addition, increased bondline thickness of the CDAA also affects the thermal resistance of the DAA region due to lower thermal conductivity of the CDAA compared to conventional DAA materials [16]. This optimization process is thus only preferable for low to mid-power LED applications (input current less than 350 mA) because junction temperature control by heat dissipation is much more crucial for such high-power LED applications in order to maintain optical performances.

Conclusions

In this study, key packaging material and process parameters for the packaged LED emitter in order to enhance light output were determined. The actual contribution of chip-level BRs to light output by two different types of BRs, and the practical role of optically transparent DAA, optimized packaging materials and process parameters were investigated at the packaged LED emitter level. Monte Carlo simulations were conducted to estimate optimal packaging parameters in light output. The results suggest that the influence of optimized packaging material and process parameters on light output is more dominant for LED emitters rather than previously reported effect by the chip-level BRs, and a simple-structured and cost effective BR-free LED chip is able to achieve an equivalent light output to a conventional BR-based chip by packaging with optimized dominant parameters.

Abbreviations

LED: Light Emitting Diode; WLED: White Light Emitting Diode; PCB: Printed Circuit Board; GaN: Gallium Nitride; BR: Backside Reflector; DBR: Distributed Bragg Reflector; DAA: Die Attach Adhesive; CDAA: Clear Die Attach Adhesive; AgDAA: Ag-based Die Attach Adhesive; MQW: Multiple Quantum Well; R_{BR}: Reflectance for the Backside Reflector; R_{LF}: Reflectance for the Leadframe Substrate.

Competing interests

The authors declare that they have no competing interest.

Authors' contributions

GK proposed the topic, established simulation models and carried out simulations.
YCS carried out experimental study and analyzed the results.
JPY analyzed the simulation and experimental results and helped in their interpretation.
FGS collaborated with the corresponding author in the construction of manuscript. All authors read and approved the final manuscript.

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References

1. Huang HW, Lin CH, Yu CC, Lee BD, Chiu CH, Lai CF, Kuo HC, Leung KM, Lu TC, Wang SC (2008) Enhanced light output from a nitride-based power chip of green light-emitting diodes with nano-rough surface using nanoimprint lithography. Nanotechnology 19(18):185301
2. Masui H, Yamada H, Iso K, Speck JS, Nakamura S, DenBaars SP (2008) Non-polar-oriented InGaN light-emitting diodes for liquid-crystal-display backlighting. J Soc Inf Disp 16(4):571–578
3. Lee C-L, Lee S-C, Lee W-I (2006) Nonlithographic Random Masking and Regrowth of GaN Microhillocks to Improve Light-Emitting Diode Efficiency. Jpn J Appl Phys 45(1L):L4
4. Chen H, Guo H, Zhang P, Zhang X, Liu H, Wang S, Cui Y (2013) Enhanced Performance of GaN-Based Light-Emitting Diodes by Using Al Mirror and Atomic Layer Deposition-TiO_2 /Al_2O_3 Distributed Bragg Reflector Backside Reflector with Patterned Sapphire Substrate. Appl Phys Express 6(2):022101
5. Lin NM, Shei S, Chang S (2011) Nitride-Based LEDs With High-Reflectance and Wide-Angle Ag Mirror + SiO_2 /TiO_2 DBR Backside Reflector. J Light Technol 29(7):1033–1038
6. Hsu YP, Chang SJ, Su YK, Chang CS, Shei SC, Lin YC, Kuo CH, Wu LW, Chen SC (2003) InGaN/GaN light-emitting diodes with a reflector at the backside of sapphire substrates. J Elec Materi 32(5):403–406
7. Yan B, Tran NT, Jiun-Pyng Y, Shi FG (2011) Can Junction Temperature Alone Characterize Thermal Performance of White LED Emitters? IEEE Photon Technol Lett 23(9):555–557
8. You JP, He Y, and Shi FG. Thermal management of high power LEDs: Impact of die attach materials. Proc., International Microsystems, Packaging, Assembly and Circuits Technology. 2007; 239–242.
9. Shih Y-C, Kim G, Huang L, You J-P, Shi FG (2015) Role of Transparent Die Attach Adhesives for Enhancing Lumen Output of Midpower LED Emitters With Standard MESA Structure. IEEE Trans Components Packag Manuf Technol 5(6):731–736
10. Muth JF, Lee JH, Shmagin IK, Kolbas RM, Casey HC, Keller BP, Mishra UK, DenBaars SP (1997) Absorption coefficient, energy gap, exciton binding energy, and recombination lifetime of GaN obtained from transmission measurements. Appl Phys Lett 71(18):2572–2574
11. Kvietkova J, Siozade L, Disseix P, Vasson A, Leymarie J, Damilano B, Grandjean N, Massies J (2002) Optical Investigations and Absorption Coefficient Determination of InGaN/GaN Quantum Wells. Physica Status Solidi (A) 190(1):135–140
12. Palmer JM. The measurement of transmission, absorption, emission, and reflection. Handbook Optics. 1995;2:25.11. http://www.photonics.intec.ugent.be/education/ivpv/res_handbook/v2ch25.pdf.
13. Xu Z, Kumar S, Jung JP, Kim KK (2012) Reflection Characteristics of Displacement Deposited Sn for LED Lead Frame. Mater Trans 53(5):946–950
14. Dow Corning Corp. Dow Corning® OE-6630 Optical Encapsulant. http://www.dowcorning.com/applications/search/default.aspx?R=6577EN.
15. Sun C-C, Chang Y-Y, Yang T-H, Chung T-Y, Chen C-C, Lee T-X, Li D-R, Lu C-Y, Ting Z-Y, Glorieux B, Chen Y-C, Lai K-Y, Liu C-Y (2014) Packaging efficiency in phosphor-converted white LEDs and its impact to the limit of luminous efficacy. J Solid State Light 1(1):1–17
16. Lin Y-H, You JP, Lin Y-C, Tran NT, Shi FG (2010) Development of High-Performance Optical Silicone for the Packaging of High-Power LEDs. IEEE Trans Components Packaging Technol 33(4):761–766
17. Fei W, Peng S, Jinlong Z, Jianhua Z, and Luqiao Y. Effect of die-attach materials and thickness on the reliability of HP-LED. Proc., International Conference on Electronic Packaging Technology (ICEPT), 14th, 2013; 1048–1052.
18. Tsai MY, Chen CH, and Kang CS Thermal analyses and measurements of low-Cost COP package for high-power LED. Proc., Electronic Components and Technology Conference, 58th, 2008; 1812–1818.
19. Chang, M.-H, Das D, and Pecht M. Junction Temperature Characterization of High Power Light Emitting Diodes. Proc., IMAPS Mid-Atlantic Microelectronics Conference, 2011; 23–24.
20. Li W (2010) A Study of Plasma-Cleaned Ag-Plated Cu Leadframe Surfaces. J Electron Materi 39(3):295–302
21. Choi S, and Ma B. Corrosive tendency of Ag plated lead frame applied to white LED. Proc., IEEE International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA), 18th, 2011; 1–3.