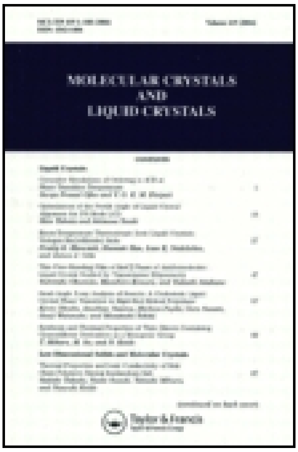

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Layer Encapsulation of Quantum Dots on Chip on Board Type White LEDs

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Version of record first published: 20 Aug 2012.

To cite this article: Seong Kwon Kwak , Tae Wook Yoo , Bo-Sung Kim , Sang Mun Lee , Seok Won Kim , Dong Wook Lee , Youngjune Hur & Lee Soon Park (2012): Layer Encapsulation of Quantum Dots on Chip on Board Type White LEDs, Molecular Crystals and Liquid Crystals, 564:1, 18-25

To link to this article: http://dx.doi.org/10.1080/15421406.2012.690642

Mol. Cryst. Liq. Cryst., Vol. 564: pp. 18–25, 2012

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2012.690642

Layer Encapsulation of Quantum Dots on Chip on Board Type White LEDs

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The chip on board (COB) types LED modules were fabricated by using metal core printed circuit board (mcPCB), aluminium oxide (Al_2O_3) and aluminium nitride (AlN) as submounts of LED chips. The radiant flux of the LEDs exhibited slight difference in terms of the LED chip bonding process in which eutectic bonding gave higher radiant flux than Ag epoxy bonding in both AlN and Al_2O_3 substrates. However the LED modules fabricated on AlN ceramic substrate exhibited higher radiant flux than the one on Al_2O_3 substrate at high current due to more effective heat dissipation in case of AlN substrate. The WLED modules encapsulated with YAG phosphor and red QD by layer-by-layer mode showed both high total luminous flux and high color rendering index.

Keywords Light emitting diode; LED; encapsulation; chip on board; MCPCB

Introduction

High efficiency light emitting diodes (LED)s have been used successfully as the LED back light unit in the TFT-LCD industry, and currently investigated actively for general lighting applications. However, thermal problem is still a bottleneck to limit the stability, reliability, and life-time of LEDs [1–4]. Therefore, effective thermal design of LED packages with low thermal resistance is critical to improve the performance of LEDs [5]. It is known that there are two general design rules for the high power operation of LED; one is the size and

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distribution of heat slug and the other is the thermal conductivity and shape of package mold. Heat slug size changes the heat path and the spreading of thermal resistance has to be taken into consideration [6,7].

The package materials for the LEDs must fulfill various requirements, including high thermal conductivity, high mechanical strength and stiffness, and high chemical inertness. The epoxy resin and silver epoxy paste have been used widely as package materials of LEDs due to easiness of processing in mold and excellent adhesion and durability [8]. However, the disadvantages of the epoxy resin are lack of chemical stability, moisture-proof ability, and relatively bad thermal properties which can limit the performance of LED chips. Ceramic materials with high thermal conductivity, good environment stability, and high moisture-proof ability have been widely used in modern electronic packaging [9] and can be regarded as a primary candidate for a package material for high power LEDs.

The development of white light-emitting diodes (WLED)s has attracted significant interest for solid-state lighting applications due to their high efficiency, long life and low-power consumption [10,11]. Multichips WLEDs, constructed by a red-, a green-, and a blue-emitting chip, show three emission bands and possess a good color rendering. However, they are expensive and need a relatively complex external detector and feedback system because each chip degrades at a different rate [12].

Single-chip WLEDs comprise only a blue InGaN chip and a yellow-emitting yttrium aluminum garnet (YAG) phosphor, so white light is produced by mixing yellow emission from YAG excited by some of the InGaN blue emission with the remaining InGaN blue light. Typical YAG doped with cerium is most widely used in single-chip WLEDs, however, such source lack red component giving lower color rendering than that of multichips WLEDs [13]. Consequently, some novel phosphors, for example, organic phosphors with flexibly selected emission color and high efficiency have been reported [14,15]. Nevertheless, the instability and long-term reliability of organic materials are doubtful.

In this work we used metal core printed circuit board (mcPCB), aluminium oxide (Al_2O_3) and aluminium nitride (AlN) as submounts of LED chips and fabricated chip on board (COB) type LED modules utilizing different silver(Ag) epoxy bonding materials and bonding methods to check their thermal properties. After optimizing LED packaging materials, the effect of red quantum dot (QD)s in addition to yellow-emitting yttrium aluminum garnet (YAG) phosphor was examined to improve the color rendering index (CRI) and efficiency of the LED modules.

Experimental

Yellow-emitting $Y_3Al_{15}O_{12}$:Ce^{3+}(YAG :Ce) phosphor and nitride red phosphor were obtained from Lumimicron Co., in Korea. The 624 nm red-emitting CdSe/CdS/ZnS core–multishell QDs were purchased from QD Solutions Co. (Daejeon, Korea) and used without further purification. The QDs were dispersed in toluene and dropped on 300-mesh perforated carbon grids to prepare the samples. The emission peak and dominant wavelength of InGaN LED chip (Cree Co. Ltd.) were 455 nm and 460 nm, respectively. The half bandwidth of the chip was in the range of 22∼24 nm. The total radiant flux of the chip was in the range of 280∼300 mW@350 mA. The dual component thermally curable silicone resin (JCR-6101 UP) was purchased from Dow Corning. Silver(Ag) epoxy resin used as die adhesive was purchased from Smitomo Co., Japan. The silicone based LED chip encapsulants were made by mixing silicone resin with YAG phosphor and red QDs utilizing the mixing/degasing machine made by Thinky Co., Japan.

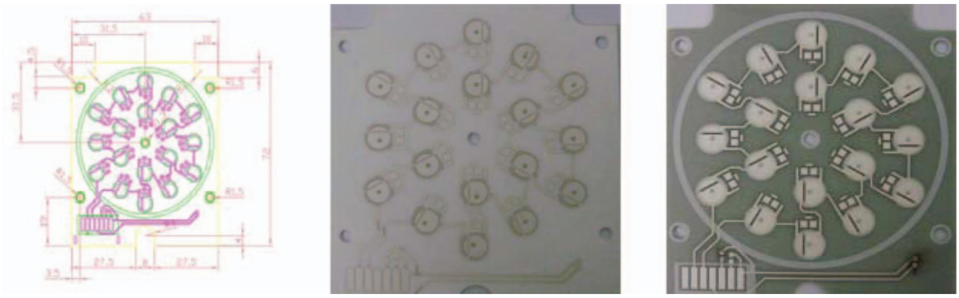


Figure 1. Photographs of LEDs (a) module circuit design, (b) on AlN ceramic submount and (c) Al_2O_3 submount.

The structure of the LED module was specially designed to enhance the thermal performance as shown in Fig. 1. The junction pad was made as 5 mm circle in consideration of the effective heat release and the wire-bonding interval of the LED chip and mcPCB pad. The phosphor containing silicone encapsulant was injected on top of the LED chips in the COB type LED module by dispensor and then thermally cured in the convection oven for 4 hours according to the curing profile. The total radiant flux of the LED chip was in the range of 280$\sim$300 mW at 350 mA. Electrode line of 1 mm width had interval of 0.5 mm to provide current to the LED module. UV–vis absorption spectra were measured using a Scinco SD-1000 UV–vis spectrophotometer. PL spectra were recorded using a Horiba Fluorolog spectrometer at room temperature with Xenon lamp as the excitation source. Transmission electron microscopy (TEM) images were obtained using an FEI Tecnai G2F30 S-Twin device at 300 kV. Optical characteristics such as electroluminescence (EL), luminous efficiency, color temperature, Commission Internationale de l′ Eclairage (CIE) color coordinates and CRI values of the WLEDs were evaluated by using the integrating sphere with Leos program.

Rsults and Discussion

The effect of using three different Ag epoxy pastes on the die bonding of LED module is shown in Fig. 2. The radiant flux of 1 W LED chip measured with the probe station (MS tech Co.) exhibited higher performance in the LED module bonded with Ag epoxy paste (sample a) than the ones bonded with other two Ag epoxy pastes (sample b and c) since the former dissipated the heat more effectively due to the higher level of percolation of silver particles in case of Ag epoxy paste(sample a). The effect of Ag epoxy paste on LED module may be explained by the different formulation of the Ag epoxy pastes. The Ag epoxy paste (sample a) had higher density and higher Ag powder content than the other Ag epoxy pastes (sample b and c). The performance of LED modules made with Ag epoxy pastes (sample b and c) were about same level as shown in Fig. 2. This could be explained by the fact that the two Ag epoxy pastes (samples b and c) had nearly same density and Ag powder content. In Fig. 3 are shown the SEM images of the three Ag epoxy pastes obtained in thin film form after drying. From the comparison of Ag epoxy pastes (sample b and c), it was noted that the size of the Ag powder was not a decisive factor on the thermal performance of LED module since the size of Ag powder in sample c was larger than that of Ag powder in sample b.

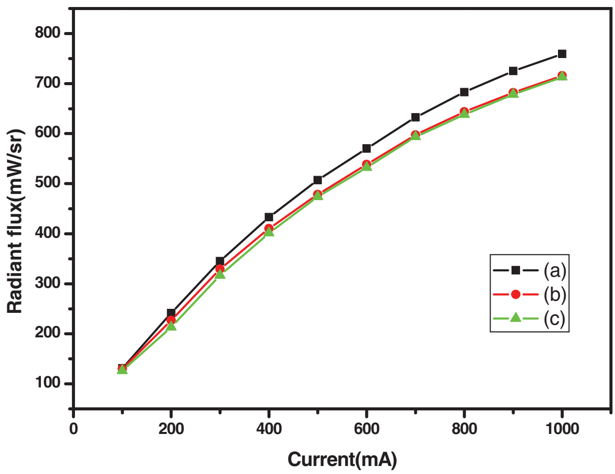
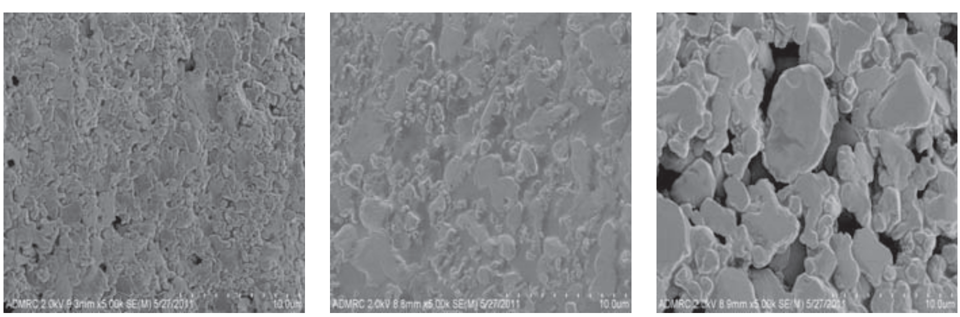


Figure 2. Radiant flux of LED modules made with different Ag epoxy pastes.

The effect of LED chip bonding material and equipment on the thermal performance of LED module is shown in Fig. 4. The radiant flux of LED module made by eutectic bonder exhibited better performance than the one by the normal silver epoxy bonder. This result could be explained by the improved heat dissipation of the eutectic bonding utilizing eutectic composition of metal alloy.

The combination of LED chip bonding methods and substrates of LED module was studied from the viewpoint of the performance of resulting LED modules. Figure 5 shows the optical power of LED modules fabricated on Al_2O_3 and AlN ceramic substrates by using two different chip bonding methods. The radiant flux of the LEDs exhibited slight difference in terms of the LED chip bonding process in which eutectic bonding gave higher radiant flux than Ag epoxy bonding in both AlN and Al_2O_3 substrates. However the LED modules fabricated on AlN ceramic substrate exhibited higher radiant flux than the one on Al_2O_3 substrate at high current due to more effective heat dissipation in case of AlN substrate.

After optimization of the packaging materials and process, the improvement of power efficiency and color rendering index (CRI) of the LED modules were studied utilizing



(a) (b) (c)

Figure 3. SEM images of Ag epoxy pastes.

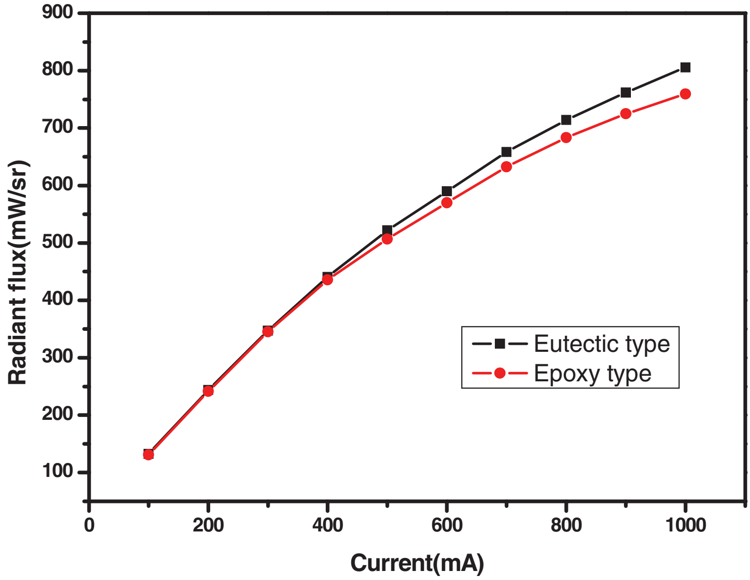


Figure 4. Radiant flux of LED modules made with different bonding methods.

the combination of YAG phosphor and quantum dots (QD)s. The single-chip white LED modules were fabricated by using blue InGaN chips and yellow-emitting YAG phosphor and red QD combination to make phosphor converted white LEDs. The PL emission peak and TEM images of the CdSe/ZnS core-shell quantum dots prepared by carbon grid method are

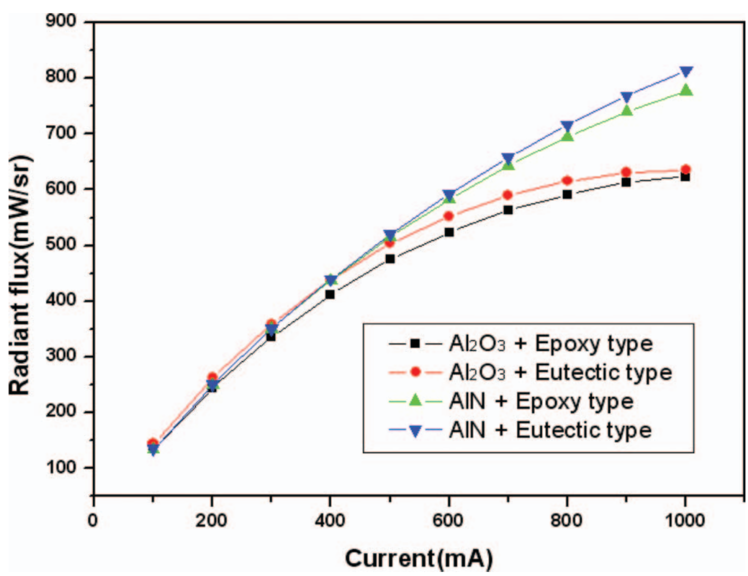


Figure 5. Optical power of LED modules vs. current plots of LED modules with different die bonding methods and substrates parameters.

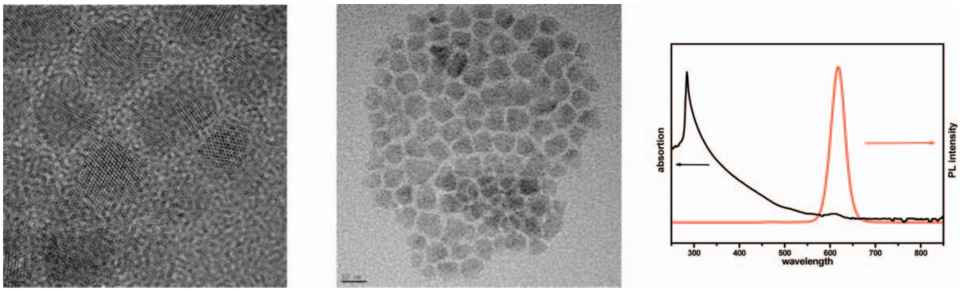


Figure 6. TEM images of CdSe/CdS/ZnS core-multishell quantum dot (QD) and UV-vis absorption and PL spectra of QD.

shown in Fig. 6. The CdSe/ZnS quantum dots exhibited uniform size distribution (average 6.5 nm) with well-defined crystalline structure and PL emission peak was at 624 nm.

We first tried to establish a reference device for the phosphor converted WLED module by using InGaN blue LED chips encapsulated with the YAG phosphor dispersed in the silicone resin. The second series WLED modules were fabricated by using the encapsulants which were made by directly mixing 10wt% YAG and varying amount of red QDs together in the silicone resin as shown in Fig. 7(a). The third WLED module was made by layer-by-layer process of phosphor encapsulation. The YAG phosphor dispersed in silicone resin was dispensed first on top of LED chips to give a small lens shape and then slightly heat cured to become tacky free. The encapsulant made by dispersing red quantum dot(QD) alone in the silicone resin was then dispensed on top of the preformed YAG encapsulant and then fully cured for 2 hours at 170°C to give WLED modules with YAG phosphor/QD layer-by-layer type encapsulation as shown in Fig. 7(b). The total luminous flux of these white LED modules were measured by using the intergrating hemi-sphere (Photal Co., Japan). As shown in Fig. 8, the WLED module encapsulated with the mixture of yellow emitting YAG phosphor and red QD exhibited higher total luminous flux but lower color rendering index than reference WLED encapsulated with only YAG phosphor. However, the WLED modules encapsulated with YAG phosphor and red QD by layer-by-layer mode showed both high total luminous flux and high color rendering index. The emission spectra (Fig. 9) of the WLEDs made by layer-by-layer encapsulation of YAG phosphor and red QD showed that the red QD peak at 620 nm appeared at low driving current of 100 mA corresponding to 6 W power while the full power of WLED module

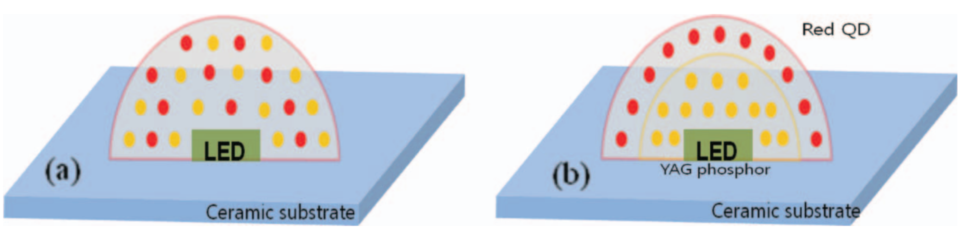


Figure 7. Schematic diagrams of LED modules with different encapsulation 9a) one layer mixture type and (b) layer-by-layer type.

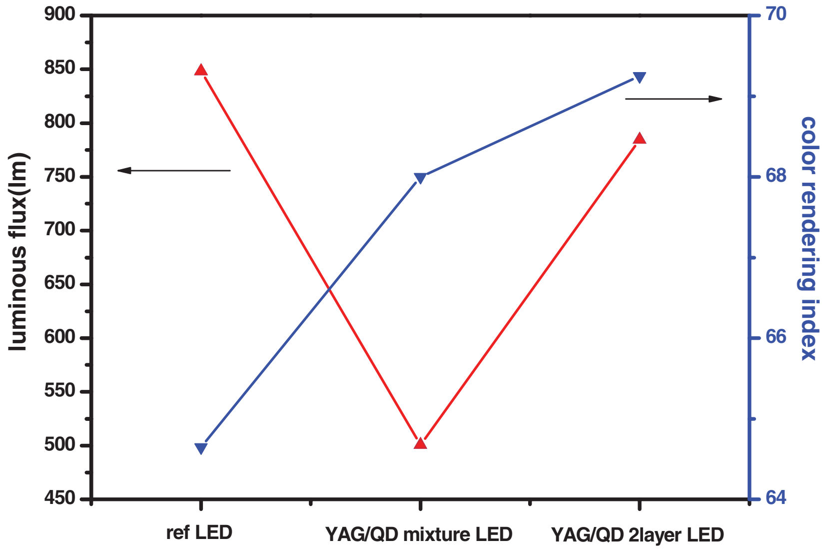


Figure 8. Luminous flux and CRI of LED.

was 18 W. These data indicate that the separate layer encapsulation of red QDs is required to increase the efficiency and CRI at same time. This result may be due to much smaller size (about 1/1000) of quantum dot than that of YAG phosphor which leads to ineffective use of quantum dots adsorbed on the YAG phosphors.

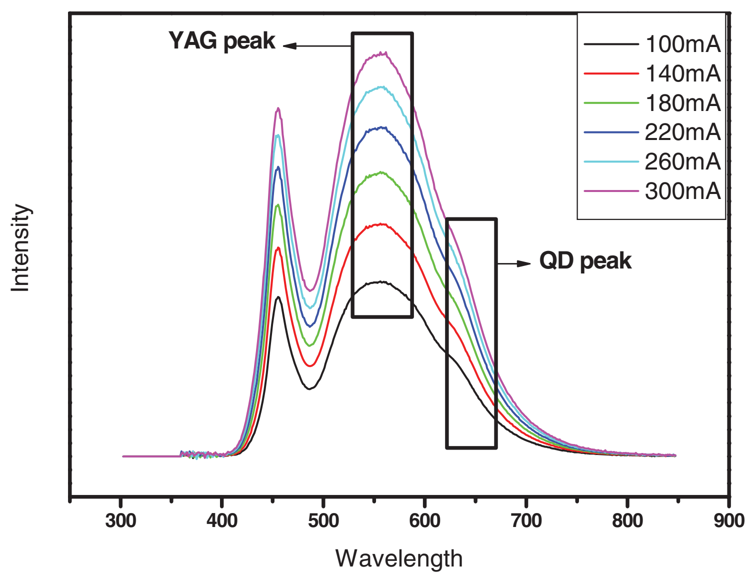


Figure 9. Emission spectra Led module with YAG/QD layer-by-layer type encapsulation at varying driving currents.

Conclusions

In this work we used metal core printed circuit board (mcPCB), aluminium oxide (Al_2O_3) and aluminium nitride (AlN) as submounts of LED chips and fabricated chip on board (COB) type LED modules. The radiant flux of the LEDs exhibited slight difference in terms of the LED chip bonding process in which eutectic bonding gave higher radiant flux than Ag epoxy bonding in both AlN and Al_2O_3 substrates. However the LED modules fabricated on AlN ceramic substrate exhibited higher radiant flux than the one on Al_2O_3 substrate at high current due to more effective heat dissipation in case of AlN substrate. The WLED modules encapsulated with YAG phosphor and red QD by layer-by-layer mode showed both high total luminous flux and high color rendering index.

Acknowledgment

This research was financially supported by the Ministry of Knowledge Economy(MKE), Korea Institute for Advancement of Technology(KIAT) and Dae-Gyeong Leading Industry Office through the Leading Industry Development for Economic Region

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