

Improvement of High-Power LED Performance with Sintered Chip Attachment

T. Wang^{1,2}, G. Lei², G-Q. Lu^{2,3}, X. Chen¹, and L. Guido^{2,3}

¹School of Chemical Engineering, Tianjin University, Tianjin, P.R. China;

²Dept. of Materials Science and Engineering, Virginia Tech, USA;

³Dept. of Electrical and Computer Engineering, Virginia Tech, USA

213 Holden Hall (0237)

Virginia Tech, Blacksburg, VA 24061

Phone: 540-231-8423

Fax: 540-231-8919

Email: gqlu@vt.edu

Abstract

High-power (HP), high-brightness (HB) light-emitting diodes are progressively making their way into the general illumination applications. Now, interconnection and packaging of the LED chips are being recognized as potential barriers for the advancement of LED lamps. Chip attachment is usually the first and important step in packaging LED lamps. The attachment material provides mechanical support, heat dissipation, and current flow for vertically conducting diodes. Since LED light output decreases rapidly with increasing chip temperature and the lamp degrades faster at high temperature, thermal performance of the chip attachment is critically important to performance and reliability of the lamps. In this study, we tested three different die-attach materials with their corresponding processes: silver epoxy processed by curing; lead-free solder by solder-reflow; and nanosilver paste by low-temperature sintering. The attached chips were tested at varying current density up to 3A/mm². We found that the chips attached using the nanoscale silver paste had a significantly higher light output than the lead-free soldered chips, which in turn had higher light output than the epoxied chips. This is explained by the higher thermal conductivity of the sintered silver than those of the solder and epoxy. Higher thermal conductivity of the sintered silver attachment resulted in a lower junction temperature at a given level of current density, thus higher light output.

Key words: LED packaging; chip attachment; low-temperature joining; nanoscale silver paste

Introduction

With the development of Solid State Lighting, the lumen efficiency and lifetime of LED chips have been increasingly improved and the application of LEDs is tending to High-Brightness Lamps in lighting technology field due to a lot of advantages of LED chip, such as high efficiency, long life time, outstanding reliability.

In the United States, about 8% of total energy and 20% of electrical energy is consumed in artificial lighting. Furthermore, 42% is consumed by incandescent lamps, emitting light indirectly from a heated filament [1]. If all incandescent & fluorescent lights are replaced by LEDs, 400 billion kW-hr electrical energy will be significantly saved, which is equivalent to reduction of 700 million barrels of oil

(~20% import), or 200 million metric tons of coal, or 5 trillion ft³ natural gas, or 140 million tons of carbon emission. The introduction of LED lighting will undoubtedly contribute to saving masses of fossil energy and indirect protection of our environment, which as an important issue is concerned by human beings recently.

However, there are still many technological challenges in solid-state lighting need to be overcome to push forward the application of LEDs, in which thermal management affecting performance, power conversion efficiency, lifetime and reliability is one of the key issues for building reliable, high lumen LED devices with the enhanced power levels and chip sizes of LEDs due to huge amount of heat in LEDs induced by the high junction temperature [2,3]. Although heat can be reduced by increasing external

Table 1 Operation parameters and properties of die-attachment materials

Die attachment materials	Peak operation Temp.(°C)	Time (min.)	Max. use temperature (°C)	Thermal conductivity (W/K-cm)	Elastic modulus (GPa)
Silver epoxy	150	10	< 200	0.1	~20
Solder paste	250	1	< 225	0.7	~60
Nano-silver paste	300	30	< 960	2.4	~10

quantum efficiency, some applications of the novel LEDs still can not keep in step with the improvement in external quantum efficiency. Meanwhile, increased heat fluxes will obviously induce thermal stress problem in devices.

Recently, a lot of works has been contributed to thermal management of HB-LED devices. Kai Zhang et al. [4] have designed a heat spreader with aligned carbon nanotubes for HB-LED packaging, whose thermal resistance was seriously reduced compared with conventional heat spreader. Thermal conductivity and coefficient of thermal expansion (CTE) of traditional and advanced packaging materials have been compared to that of semiconductors and ceramic substrates in order to find out a suitable packaging material with good performances in thermal disperse and CTE match with LED chips and substrates, which would benefit thermal management and lower thermal stress in LED devices [5]. Mehmet Arik et al. [6] reported that defects in chip and die-attachment could cause significant thermal gradients across the LED chips and improve the junction temperature of LED, leading to premature failures, therefore defective chips and die-attachment should be avoid during fabrication and packaging of LED devices. K.C. Chen et al. [7] have developed and proposed a novel package using copper electroplating without resin between chip and substrate for ultra power light LEDs (UPLLEDs), this kind of LED device compared to conventional one could improve heat dissipation and lumen intensity of UPLLEDs. Albert welsh Jr. et al. [8] have investigated the reliability aspect of the LEDs based on a comparison of different types of die-attach epoxies used in the package of LEDs, the experiment results demonstrated that the loss of the LOP of LEDs was affected by both the heat from the chip and the absorption properties of epoxy as an interconnection material.

Although some scientists have strived to further thermal management considering different thermal problems in the package of LED devices, little researches on developing a novel material for die-attachment were reported since the thermal resistance of the material between LEDs and substrate was critical to the heat conduction [9]. In

this paper, an alternative nano-silver paste was firstly brought into the package of LED devices, and some experiments concerning on the usage of this advanced interconnection materials would be carried out as follows.

Experiments and discussions

In this study, we have examined the performances of a high-power, blue GaN-based LED with Au back coating (1 mm×1 mm in size) attached to a direct-bond-copper (DBC) substrate (electroless plated with Au/Ni) using three different types of die-attach material for comparison: (1) silver-filled epoxy from Emerson & Cuming, Inc.; (2) lead-free solder paste (95.8Sn-3.5Ag-0.7Cu); and (3) nanoscale silver paste, nanoTach® from NBE Technologies, LLC [10]. Stencil-printing technology was employed during die-attachment process. For nano silver paste, a low temperature sintering technique was introduced into the mounting semiconductor device onto metallized substrate [11, 12]. Table 1 lists the operation parameters and properties of the proposed three chosen die-attachment materials. The thicknesses measured by microscope of those die-attachments were about 20 μm after heating process.

After attachment, the chips were wire-bonded with gold wires for electrical connection. Tests were completed under a microscope outfitted with a silicon detector at the camera port for measuring relative light output as a function of electrical current. In order to measure the general performances of LED devices, a fine thermocouple was mounted on the edge of LED chip, thereafter it was placed on the substrate close to the chip site to monitor temperature rise for degradation tests on other LED samples, because direct measurement for thermocouple on LED would probably cause thermal spot on LED which should damage chip and influence the degraded action of the chip with rising injected current. The LED device and equipment for testing were shown in Fig.1 and Fig.2.

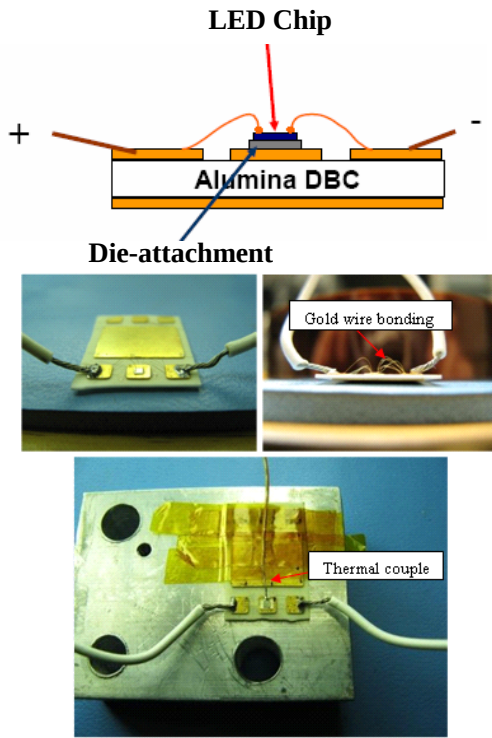


Fig.1 LED device

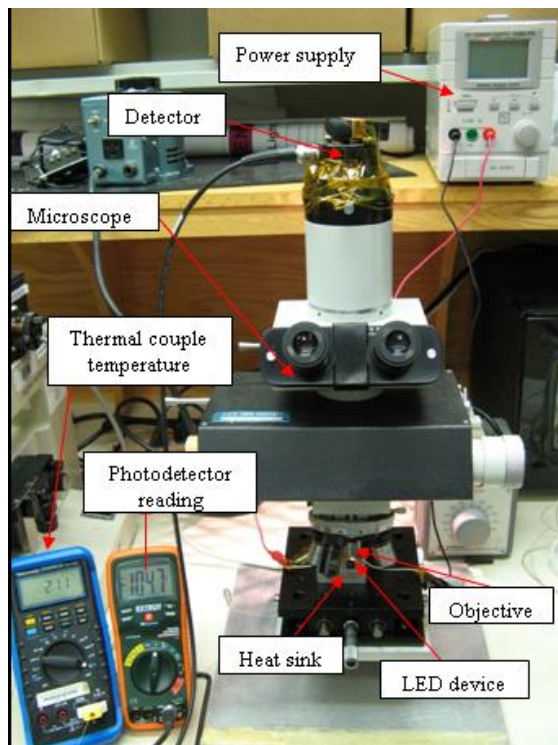
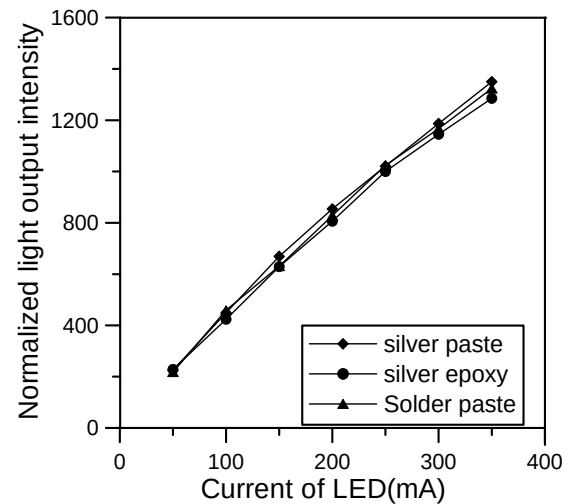


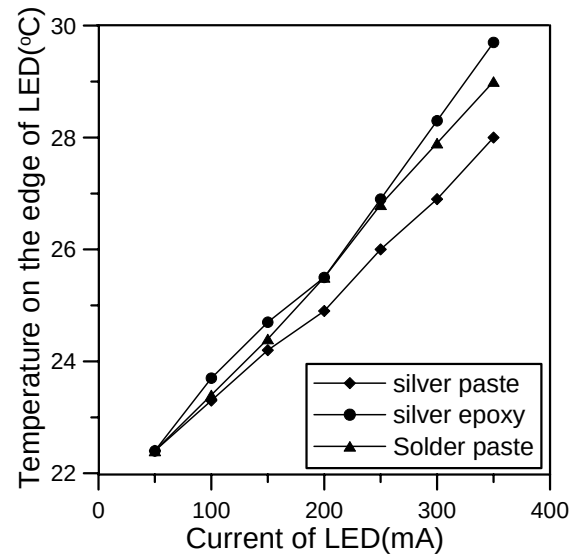
Fig.2 Experiment setup

- (1) General performances of LED device
The ambient temperature was 20°C in the

tests. The LED devices were turned on at different current (50, 100, 150, 200, 250, 300, 350mA), the output light of chips was captured employing the detector and the edge temperatures of LEDs were measured at each current level as soon as possible. The intensities of those samples were almost the same at the instant low currents, meanwhile, it could be indirectly obtained that the junction temperature of the LED chip increased when driven at a higher current [13], however, the temperature on the edge of LED attached using silver epoxy and solder paste were higher and higher than silver paste with the rising current as shown in Fig.3.

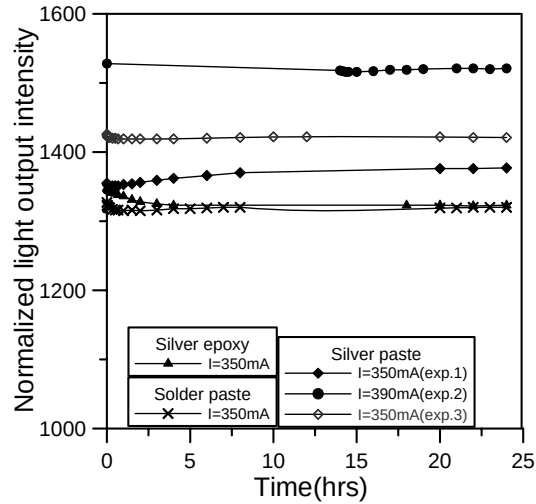


(a)

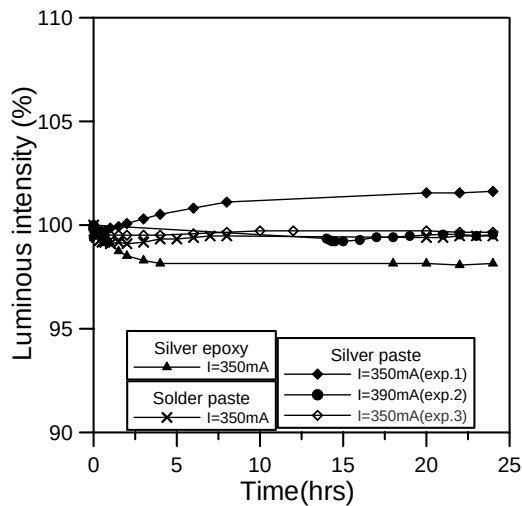


(b)

Fig.3 (a) current-Normalized light output intensity;
(b) current-temperature on the edge of LED



a) Working time-Normalized light output intensity



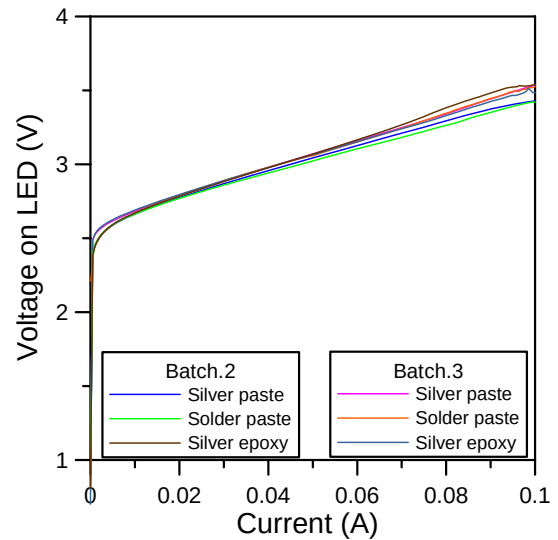
(b) Working time-Luminous intensity change

Fig.5 Short-time working performance

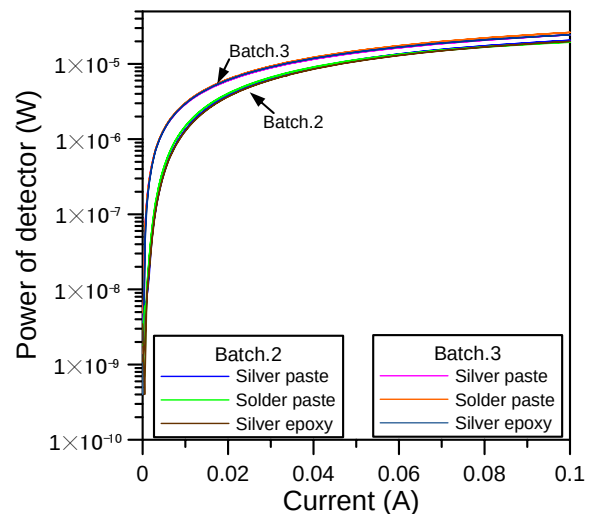
A short-time working performance of LEDs was studied to make a distinction of those various die-attachment materials. For the LED device attached with silver paste, the change of emission intensity with proceeding time was investigated when the injected current equaled to 350mA for 24 hours firstly, then 390mA, at last tested the LED working at the current of 350mA again. For the other devices, only working performance at the current of 350mA was tested. Inspection of Fig.5 (a) and (b) indicated that the luminous intensity of LED attached with silver paste was enhanced in 24 hours at current of 350mA and almost keep stable at 390mA and in the following test at 350mA, rather than decrease for those attached with silver epoxy and solder paste, which revealed that the working performance of LED

device interconnected with silver paste was better at the working current of 350mA attributing to the high thermal conductivity of sintered silver. Even when the current was higher than 350mA, such as 390mA, the emission intensity of LED with silver paste tended to fall, but the loss of intensity was still smaller than the LED interconnected with silver epoxy working at 350mA. The temperature on LED attached with silver paste was lower than that with solder paste, and which was in turns lower than that with silver epoxy at 350mA.

(2) Accelerated degradation of LED devices



(a) I-V curves

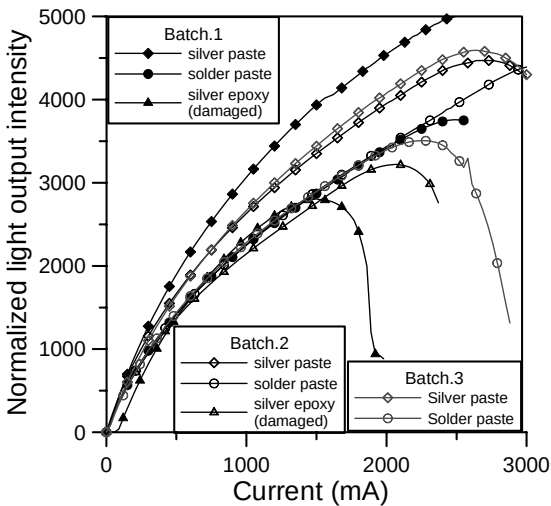


(b) L-I curves

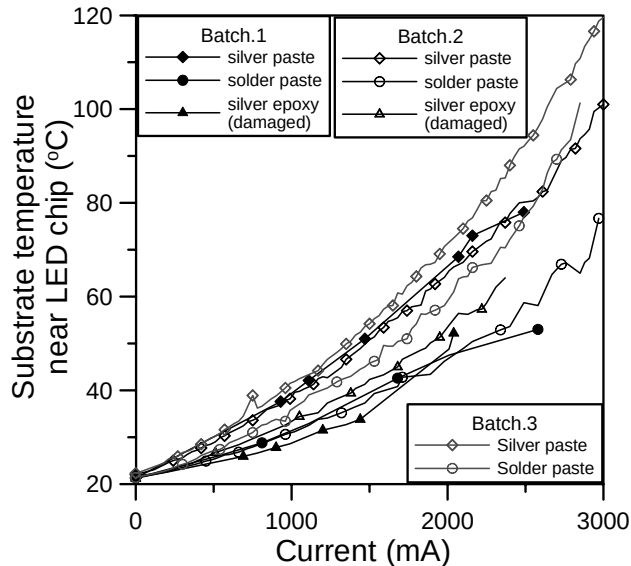
Fig.6 L-I-V characters of LED chips from batch.2 and batch.3.

Three batches of LED chips were used for evaluating the accelerated degradation of LED

devices interconnected with different materials, in which LED chips in batch.1 were randomly selected from dozens of LEDs. Those in batch.2 and batch.3 were selected by screening chips for comparable L-I-V characteristics as shown in Fig.6, so as to evaluate the impact of different interconnection materials on accelerated degradation experiments objectively. The interconnected chips were tested at current-density levels up to 3A/mm^2 and the rising rate of current was 6mA/s .



(a) Current-normalized light output intensity curves



(b) Current-substrate temperature curves

Fig.7 Accelerated degradation of LED chips

Fig.7 depicted the accelerated degradation of LED chips. If the interconnection material was silver paste, the relative light output intensity of LEDs were highest at the same current, getting higher and higher

than the devices attached using silver epoxy and solder paste with the increasing current. For batch.1, the LED attached with solder paste degraded when the current equaled to 2.5A , and the LED was not damaged for silver epoxy until the LED was driven up to 1.5A . For good thermal conductivity of silver paste, intensity drop didn't appear even at 2.5A .

When observing the degradation of batch 2, LED interconnected with silver epoxy was damaged like the former one and all the gold wires were broken away from gold balls rather than in the middle of gold wires as usual perhaps due to high temperature on the surface of LED when the injected current rose to 2.4A as shown in Fig.9, intensity drop of this sample happened at the current of 2.1A . For the LED using solder paste as an interconnection material, no degradation made an appearance even with the current of 3A . For silver paste as an interconnection material, the LED degenerated when the current was about 2.8A . But compared to the chip with solder paste, LED attached with silver paste was brighter and the junction temperature was lower since the more heat was dissipated from chip to substrate, the higher temperature on substrate was obtained at the same location then the lower junction temperature would present and vice versa.

In batch 3, the degradation of the LED using solder paste as an interconnection material appeared with the current of 2.3A in the same testing. For silver paste as an interconnection material, the emission intensity was in decline when the LED was driven up to 2.7A .

Undoubtedly, the junction temperature increment lowers the performances of LED devices on efficiency, optical output power, causes the peak wavelength to shift and reduces reliability of the devices [14]. The experiment results proved that the high power LEDs interconnected with nano-scale silver paste were better than with traditional die-attachments in reducing junction temperature, meanwhile, the heat produced by LEDs definitely affected the performance of those devices.

Furthermore, because of the presence of the porous structure making for low elastic modulus of sintered silver [11], and it was well known that a softer interconnect material can serve as a better mechanical buffer layer since it transfers less of the thermally-induced stresses from the semiconductor-substrate CTE mismatch, the sintered silver as a more reliable semiconductor-substrate interconnection should have better thermomechanical properties than either solder alloys or cured silver epoxies.

Conclusion

In brief, the high power LEDs attached with a novel interface material were proposed and

fabricated. It was observed that the thermal resistance of the interconnection materials for thermal conduction played a significant role in thermal distribution of the LEDs. Based on our study, the sintered silver paste for its high thermal conductivity would not only efficiently contribute to heat dissipation but also enhance the performances of LEDs. Obviously, thermal management was critical for improving the performance of high-brightness LEDs in solid state lighting application. Nanoscale silver paste as an alternative die-attach solution, having high thermal conductivity and low elastic modulus helpful for thermal management, was an excellent die-attachment for HB-LEDs, which can substitute for traditional die-attached materials in LED lighting industry.

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